Sourcebook 3
Galaxy

About this book

This is the third sourcebook for Macross 2050. This book contains the information about any groups not covered in the previous two sourcebooks, as well as information to create new star systems to explore and colonize.

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Preface

The Milky Way Galaxy is very large, and filled with billions of stars. Each of those stars has the potential for planets, and those planets the potential for signs of life. Whether such a planet has active life or just the ruins of past civilization, many lessons may be learned. Humanity was brought to the brink of extinction in the blink of an eye, and now with their Zentraedi brethren, they will spread out into the stars to form a new Stellar Republic. Only this time, pray we learn from the mistakes of the Protoculture.

Chapter 1 – Civilians

Even in a game of mecha combat, the average civilian is still a major part of the story. Civilians fill the role of providing services, manufacturing goods, colonizing worlds or just living. Sometimes a civilian is forced into the role of becoming a hero (Hikaru Ichijyo started as a civilian stunt pilot after all). Good examples of civilians include Lynn Minmei, Akiko Hojo, Myung Fang Lone, Guld Goa Bowman, Sheryl Nome, Ranka Lee, Alto Saotome and Nekkei Basara.

Some civilian templates can still work with a military group by buying the Membership perk. This can represent such characters as a stellar archaeologist who works with the UN Spacy, members of a private military contractor, or a mechanical engineer that is willing to do repairs for an anti-UN group. Private military contractors fall into this group.

<u>Civilian – Basic Colonist/Joe Average</u>

This includes the multitudes of non-specialized colonists and civilians found throughout

the galaxy.
Skills: Drive, Computer Operation, Mathematics, choose 4 skills to represent their profession (only 1 skill may be "difficult")

Civilian Media – Investigative Reporter/War Correspondent

The media will always be a part of humanity. This includes all types of credible reporters as well as shady individuals who write for the trash tabloids.
Skills: Credibility, Awareness/Notice, Composition, Human Perception, Social, Photo & Film, Interview

Civilian Gang Member – Bikers/Punks/Etc.

This group includes a lot of juvvies who don't fit well into society; bikers, gangs, boosters, dealers, etc.
Skills: Streetwise, Motorcycle, Melee or Handgun, Intimidation, Pick Pockets or Lockpicking, Brawling, Awareness/Notice

Civilian – Stellar Archaeologist

Stellar archaeologists study ancient Protoculture ruins as well as other ancient planetary phenomena to learn more about the ancient past. Many work alongside the OSSSF.
Skills: History, Archaeology, Anthropology, Relicology, Awareness/Notice, Mathematics, Research

Civilian – Mechanical/Electrical Engineer

This includes civilian contractors such as Viggers/Chrauler, Centinental Corporation and Shinsei Industries as well as the average Joe running a car repair shop.
Skills: Jury Rig, Mathematics, Computer Operation, choice of 4 TECH skills

Civilian – Scientist

This includes members of the scientific community. They could work with the UN government or be individual researchers.
Skills: Mathematics, Research, Computer Operation, choice of 4 INT and/or TECH skills

Civilian – Medic

Private physicians, hospital staff and other specialists.
Skills: Med Tech, Awareness/Notice, Diagnose Illness, Pathology, Research, Pharmaceuticals, Human Perception

Civilian – Pilot

This includes anyone from commercial shuttle pilots, delivery drivers and even flight tour

guides.
Skills: Astro-Navigation, Mathematics, Radio Communication, Pilot: Spacecraft, Navigation, Astronomy

Civilian – Religious

Mainstream religious leaders, cult leaders and the like.
Skills: Religion, Expert (choice based on religion), History, Charismatic Leadership, Social, Persuasion, Interrogation

Civilian – Private Military Contractor

Use appropriate templates from Sourcebook One, but apply Membership or Rank to the military provider group rather than the UN. Keep in mind most civilian military providers have Exception Clause B that states "when the parent government enters into war, members may not refuse orders to fight nor may they resign their commission".

Chapter 2 – Law Enforcement

This chapter covers law enforcement groups and has a listing of typical punishments for various crimes. Military police are covered in Sourcebook 1.

Galaxy Patrol

The Galaxy Patrol is a join venture of the Earth United Nations and its allied planets to patrol the space surrounding the colonies. The Galaxy Patrol searches for rogue Zentraedi/Meltrandi fleets, smugglers, ships in distress or any other threats and/or problems. Members of the Galaxy Patrol receive training in basic mecha skills and military/police protocols and tactics.

Because the planet of Zola is so peaceful, the branch of the Galaxy Patrol stationed on Zola has the primary duty of stopping poachers from killing the galactic whales that pass by the planet every year during their migratory cycle.

The Galaxy Patrol draws its members from UN Spacy military as well as civilians who want to join. Galaxy Patrol mecha are almost always armed with non-lethal weapons (see Tech Manual). Although the Galaxy Patrol is a subsidiary of the UN Spacy, it has enough autonomy to perform its functions without needing much supervision.

There are approximately 35 Galaxy Patrol fleets in service as of 2046, each being roughly the same size. Each fleet has approximately 4 Ark Royal Escort Carriers, 6 Clemenceau Class Stealth Frigates and 10 Northampton Class Stealth Frigates. Also, 20 of these fleets are lead by a New Macross Class Battle Carrier. (By 2050 increase the number of fleets to 40, with 23 lead by New Macross carriers.)

Law Enforcement – Galaxy Patrol

The Galaxy Patrol often works with the UN Space Navy to protect UN controlled and allied space from criminal activity and minor Zentraedi disruption.
Skills: Authority, Handgun, Athletics, Hand-to-Hand, Interrogation, Streetwise, choice of Mecha Pilot: VF or Pilot: Spacecraft

Police & SWAT

Almost all colonies, Megaroad/Macross class colonial ships, and space stations have a local police force. These police are not much different than those of the late 20th Century, although they have access to better technology and they have the power and authority to do their job without fear of being sued for every little thing.

A subsection of the police is SWAT, who receive anti-terrorist training and use heavier weapons and armor than standard police. SWAT personnel are typically authorized to use deadly force to bring down terrorists.

Law Enforcement – Police

This includes the standard police force, plain clothes cops and private security forces maintained by large companies.
Skills: Authority, Handgun, Human Perception, Athletics, Hand-to-Hand, Interrogation, Streetwise

Law Enforcement – SWAT

SWAT and other anti-terrorist groups receive extensive training for the purpose of taking down rebel Zentraedi and other violent criminals.
Skills: Stealth, Athletics, Expert: Counter-terrorism, Tactics, Automatic Weapons, Hand-to-Hand, choice of Handgun, Rifle & Shotgun, Heavy Weapons

Police Rank (3 OP per rank)
Rank 1 – Policeman
Rank 2 – Senior Policeman
Rank 3 – Police Sergeant
Rank 4 – Assistant Inspector
Rank 5 – Police Inspector
Rank 6 – Superintendent
Rank 7 – Senior Superintendent
Rank 8 – Chief Superintendent
Rank 9 – Superintendent Supervisor
Rank 10 – Superintendent General

Note that any given police organization will not have more than one person of each rank above 8. Players shouldn't advance beyond Rank 5.

Crime & Punishment

A listing of typical crimes and their suggested punishments. All punishments refer to a 1st offense; increase the duration/fine by 25-50% for each additional offense (except in cases of life incarceration or death penalty), excluding Minor Crimes.

Crime	Punishment
Minor Crimes[1]	1-6 weeks jail time and/or a fine
Theft, Major[2]	4-24 months jail time
Theft, Grand[2]	10-30 months jail time
Illegal Firearm Possession	6-48 months jail time

Driving Under Influence (DUI)	2-8 weeks jail, fine, license revoked
Manslaughter, Unintentional	3-24 months jail time
Manslaughter, Intentional	Lifetime sentence
Violent Crime[3]	5-15 years jail time (1d6+4)
Violent Crime with a warmachine[3]	4-40 years jail time
Financial Crime[4]	2-8 years jail time and/or fine
Treason[5]	Death by firing squad or spacing
Ecological Crime[6]	5-30 years jail time and fine
Cybernetics[8]	Variable
Galactic Whale Poaching	4-16 months jail time
Smuggling, Black Marketeering[7]	4-20 years jail time and fine
Theft, Use, or Sale of Reaction Weaponry[5]	Death by firing squad or spacing

1 – Includes such things as vandalism, traffic violations, public indecency, shoplifting of minor objects and most other gang mischief related crimes. Instead of incarceration, the subject may be fined an amount from 100 to 2000 credits. Minor theft (less than 500 credits value) may be fined up to five times the value of the stolen goods, either in place of or in addition to incarceration time.
2 – Major theft includes all properties with value from 500 to 10,000 credits. Anything above this amount goes into grand theft.
3 – Violent crimes include, but are not limited to: armed robbery, taking a hostage, assault with a deadly weapon, rape, assault & battery, "domestic" terrorism (drive-by shootings and such) and attempted homicide. Use of a mecha or other combat-capable vehicle increases the length of incarceration.
4 – Financial crimes include embezzlement, fraud, and other crimes involving finances other than direct robbery. Typically these crimes face a time of incarceration as well as restitution of up to ten times the amount of credits in question.
5 – This includes being a member of an Anti-UN group. This may be reduced to lifetime incarceration if the defendant is proven to have been a non-violent member or pressed into service unwillingly. Some colony fleets space criminals instead of using a firing squad.
6 – With the importance of terraforming and colonizing a new world, environmental issues become very important. The illegal dumping of toxic substances, planetary debris, and scrapped mecha/capital ships is highly prohibited outside of designated sites. This carries a heavy fine of up to millions of credits as well as a mandatory period of incarceration.
7 – Unless it pertains to reaction weaponry, then it becomes Treason.
8 – Cybernetic legality varies between colonies and fleets. The penalty for breaking local law will usually include a fine and banishment from said colony/fleet or removal of implants if it not extensive.

Chapter 3 – The Anti-UN

When the Inspector Army gunship crash landed on South Ataria Island, the governments of the Earth were locked in a civil war. The realization that humans are not the only life in the galaxy, and obviously not the most advanced, made many of the governments join together to form the Earth United Nations. Not everyone liked the idea.

Multiple times during the reconstruction of the SDF-1, the UN was attacked by terrorist groups and paramilitary units that wanted to overthrow the UN, even if it meant eliminating their only defense against invaders (most anti-UN believed the "alien threat" was a hoax to get other governments under the UN's thumb). After the Zentraedi joined the survivors of earth, many of them did not adjust well to the life of a civilian, or they were just plain mad for being defeated by such an "inferior" enemy. These Zentraedi joined Anti-UN forces or created their own all-Zentraedi groups (for the ones that hate humans). During the development of the VF-0, the plans and technology were stolen and the anti-UN forces built a SV-51 variable fighter.

Among the more infamous groups are the Zentraedi groups Vindirance and Struggle, and the Free York Liberation League. Being a member of an Anti-UN group is listed as treason under current laws, and usually means execution or a lifetime sentence in a maximum security prison.

Terrorists and Anti-UN personnel must take the Secret Identity complication if they wish to remain unknown, otherwise they must take the Enemies complication to indicate they are known and wanted.

In 2050, a terrorist group backed by the Critical Path Corporation, known as the Black Ravens, and lead by Timoshie Daldanton cause great distress to the UN government. The Critical Path Corporation develops an anti-FCS (fire control system) that disables the target's weapons so they cannot fire. In early 2051, they install this system on the SDF-1 Macross and hijack it, destroying a large part of the earth defense fleet. The jamming device is disabled by pilot Aegis Focker, allowing the remainder of the fleet to destroy the Macross.

<u>Anti-UN/Terrorist</u>

Some Anti-UN forces are pure Zentraedi or human, while other groups are mixed. This represents non-professional military members.
Skills: Automatic Weapons, Dodge & Evade, Wilderness Survival, Demolitions, Streetwise, choice of Hand-to-Hand, Melee, Brawling

Chapter 4 – Criminals & The Black Market

Ever since the creation of civilized trade, there was the black market. If you can't afford, find, or legally own something, the black market can usually get it for a price. They deal in drugs, information, military hardware, mercenaries, or even the simple things such as chocolate (where it's normally unavailable). Many Anti-UN and terrorist groups have long standing arrangements with the black market, and sometimes offer services in exchange for goods.

The black market has some specialized sub-markets as well; one of them being a market for Galactic Whales. Galactic Whales can travel in space under their own power, even capable of superluminal flight faster than the best technology can achieve. However, if a warp engine is manufactured with substances from the Galactic Whales, they run much more efficiently. Other sub-markets include drugs and military weapons.

The Loschier Company – One of the biggest Black Market operations in the galaxy. They have a semi-permanent base of cargo ships (stolen of course) docked

together in an asteroid belt. They are big enough of an outfit to actually distribute a catalog of what they have or can get.

Civilian – Smuggler/Dealer

This includes individuals who deal in contraband of one form or another; either moving it or selling it.
Skills: Streetwise, Concealment, Intimidation, Persuasion & Fast Talk, Awareness/Notice, Handgun or Melee, Dodge & Evade

A longstanding tradition from before Space War I survived and was rebuilt; the Mafia. Through use of the Galaxy Network, the mafia families are able to maintain communications and conduct business as normal. The "modern" mafia includes remnants of the old yakuza and triad groups that were preserved on the SDF-1 from Macross Island as well as those who rebuilt the Italian families. The mafia does dealings with various smugglers and black marketers as well as maintaining legitimate business fronts.

Civilian – Mafia Businessman

This includes any of the "gentlemen" of the family and those who have authority within the Mafia.
Skills: Authority [mafia], Streetwise, Human Perception, Intimidation, Accounting, Forgery, Expert: Criminal Groups

Civilian – Mafia Thug

This group includes the drivers, leg-breakers, bodyguards, assassins and cleanup experts that work for the Mafia.
Skills: Handgun, Drive, Awareness/Notice, Dodge & Evade, Rifle & Shotgun or Automatic Weapons, Intimidation, Concealment

Chapter 5 – The Galaxy Network

The Galaxy Network started out as an information network established by UN Spacy to keep all of the colonies and fleets in contact with each other for quicker distribution of information. Eventually it evolved to include a civilian broadcasting network for music, news and entertainment – not unlike cable TV of the late 20th century.

Many bands and singers try hard to make it on the Galaxy Network Chart (think MTV Top 10). After the rapid rise of popularity for the band known as Fire Bomber, the music scene has been almost overrun with bands trying to grab their 15 minutes of fame. There have also been some copycat bands trying to imitate Fire Bomber (such as British Bomber and Fire Bomber American) – and becoming popular regardless.

In 2045-2046 there are many bands and singers regularly broadcast on the Galaxy Network – Fire Bomber, Bamboo-road Express, Alice Holiday, Flaschakaya, Power of Tower, Fascinate Miles, Metarism, Tomo Cherry Spring, Wild Honey, Kamal Hazaar, Lark Skybeauty, Panther, Daniel Akkerman Orchestra, King and Queen, and Mosaic – and of course classics like Linn Minmei and Sharon Apple. Even the distant world of

Zola broadcasts its ZZNKQB Zola radio station on the Galaxy Network. In 2047, both British Bomber and Fire Bomber American get their songs on the Galaxy Network despite being copycats.

The Virtual Net is a part of the Galaxy Network, broadcasting educational material to the colonies and fleets so the children of the colonists can receive schooling. The Galaxy Network also has many of the same features and uses as the Internet of the late 20th Century.

Galaxy Network Chart Top 10 (on 1/21/2046)
1 – Alice Holiday (Galaxy)
2 – Fire Bomber (Sweet Fantasy)
3 – Lynn Minmei (Angel's Paints)
4 – Flaschakaya (Because that is the Future)
5 – Power of Tower (Groove Along)
6 – Metarism (Drive the AZ Highway!)
7 – Sharon Apple (Santi-U)
8 – Tomo Cherry Spring (Debut Earth: Birthplace)
9 – Daniel Akkerman Orchestra (Mark Twain's Lovers)
10 – Fire Bomber (Planet Dance)

Galaxy Network Best Selection
1 – Fire Bomber (Rock 'n Roll Fire)
2 – Fire Bomber (Koi no Mahou)
3 – Kamal Hazaar (Meditation)
4 – Wild Honey (Black-White)
5 – Lark Skybeauty (Yuureisen A Phantom Ship)
6 – Fire Bomber (Love Song)
7 – Panther (Ore Ga Subete Da)
8 – Milky Way (Galaxy Breeze)
9 – Fire Bomber (Goodbye)
10 – Fire Bomber (Pillow Dream)
11 – Lark Skybeauty (Halation)
12 – Fire Bomber (Hello)

Civilian Entrepreneur – Producer/Manager

This includes individuals such as Akiko Lips and others who either promote, maintain or otherwise back a singer or band.
Skills: Awareness/Notice, Human Perception, Composition, Social or Seduction, Persuasion & Fast Talk, Wardrobe & Style, Personal Grooming

Civilian Entertainer – Singer/Band Member/Idol/Actor

This includes those who perform either as amateurs or as professionals. This includes singers, bands, actors and dancers.
Skills: Charismatic Leadership, Awareness/Notice, Perform, Wardrobe & Style,

Composition, Play Instrument, Dance or Acting

Famous Bands/Singers

Lynn Minmei – Even 40 years after her debut, several of Minmei's songs remain famous; Do You Remember Love and Angel's Paints in particular (the song that stopped the Zentraedi and her last song, respectively). Dr. Chiba was inspired by Minmei's songs to create his sound energy theory.

Sharon Apple – Despite the fact she was a virtual idol, and that she tried to take control of Macross City, a few of Sharon's songs remained popular; particularly I Want to be an Angel, Santi-U and Information High.

King and Queen – A lesser known band that is reminiscent of the 20th century band Queen or X Japan.

Mosaic – Another lesser known band that specializes in techno.

Alice Holiday – She is well known for her love ballads. Before the rise of Fire Bomber, Alice held the #1 spot on the Galaxy Network Chart for several months.

Fire Bomber – Their fame and songs will be well known for ages. After the Varauta/Macross 7 war, there were several copycats, such as Fire Bomber American.

Milky Dolls – This is a group consisting of five female idol singers. They were captured by anti-UN forces on July 23, 2047 and then rescued by UN special forces.

Sheryl Nome – The "galaxy fairy" is a 17 year old singer on the Macross Galaxy fleet in 2059. She maintained the #1 spot for fifteen weeks straight.

Ranka Lee – A young girl on the Macross Frontier fleet who earned the nickname of "Galactic Cinderella" by becoming a rival to Sheryl Nome from out of nowhere.

Famous Managers

Lynn Kaifuun – Actor and cousin of Lynn Minmei. He worked as her promoter and manager during the rebuilding in 2010-2011. He then later went on to become manager of Fire Bomber American aboard the Macross 11 fleet.

Akiko Hojo – She works under the moniker of Akiko Lips. She promoted Fire Bomber, officially.

Grace O'Connor – Manager responsible for "creating" Sheryl Nome.

Elmo Kridanik – Manager and owner of Vector Promotions. He brought Ranka Lee into the spotlight.

Chapter 6 – Companies & Manufacturers

This chapter details some of the companies and manufacturers of the destroids, variable fighters and other technologies. Being mostly democratic, the New Unity government allows free enterprise and business, although they do have more control over costs for commodities that are essential to life (such as medical care) and place severe restrictions on technology that is too dangerous for the open public. Many corporations cater specifically to the UN government.

Civilian Entrepreneur – Corporate/Investor

These are the leaders of big money corporations and industries; those who make executive decisions and deals with potential customers.

Skills: Stock Market, Human Perception, Research, Social, Persuasion & Fast Talk, Wardrobe & Style, Awareness/Notice

Major Corporations

Listed here are some of the largest and more well known companies in the Macross saga. Being associated to one of these big companies costs 2 OP per Rank.

OTEC – This was the original group founded in 1999 to reverse-engineer the Protoculture's gunship that landed on South Ataria Island. It was OTEC that designed the thermonuclear reactor engine, the pinpoint barrier system and the hyper-alloy materials for their armor. They also developed reaction weaponry.

Stonewell-Bellcom – Developed the VF-0/VF-1, VF-4 and the Destroid MBR & HWR series.

Shinnakasu – Co-develops the VF-5000 with Stonewell-Bellcom. Before merging with Stonewell-Bellcom, Shinnakasu was the leading manufacturer of thermonuclear turbine engines.

A heavy Industry Manufacturer that managed the reaction engines in the VF-1's development. The core products are wide ranging, from aircraft and space ships up until automobiles. Popularity is high among old car enthusiasts for such things as Shinakasu's sports cars and the Red Imperial, which were released before the First Interstellar War. There is a theory that this enterprise was incorporated during the reorganization of Japan's main domestic industries in the confusing period of the falling of the ASS-1, the Unification War and so on.

General Galaxy – Founded by ex-science officer of the Zentraedi Boddole Zer fleet, Algus Selzaa, their first project given to them by UN Spacy was the design and development of the VF-9 Cutlass, and later the VF-17 Nightmare. During Project Super Nova, they offered the YF-21. General Galaxy specializes in developing stealth fighters.

An enterprise that was born from the amalgamation several companies with OTEC, who had born the burden of implementing Overtechnology. General Galaxy developed the YF-21, which had fought against the YF-19 to be the next version of the main craft. General Galaxy is the rival of Shinsei Industry.

Shinsei Industries – This company was formed from the merging of Shinnakasu and Stonewell-Bellcom in 2012. Developed the VF-11 Thunderbolt and VF-16. During Project Super Nova, they offered the YF-19 designed by Yang Neumann. They went on to create the YF-24. They are sometimes listed as Shinsei Heavy Industries.

Northrom Grumman – Developed the VA-3 Invader. Co-developed the VB-6 with Shinnakasu. Specializes in heavy bomber technology. Also developed the Masamune battroid.

Mikoyan – This company co-developed the VAB-2 with Northrom Grumman, and the VA-14 with General Galaxy. Specializes in stealth bomber technology.

Messer – This company co-developed the VF-14 with General Galaxy.

Viggers & Chrauler Corporations – Manufactures of heavy destroid and heavy weaponry technology. Designed the HWR technology.

After the ASS-1 fell, the human race who knows of the existence aliens, started the development of anti-giant humanoid weapons. During that, even though a lot of enterprises were participating, Viggers existed centrally among them. The Monster, as well as such things as the Tomahawk, Defender and so on, which were put into the First Interstellar War, were developments of this company. Viggers is considered to have originally been the military vehicles department of an armaments development enterprise that became an independent business.

Centinental Corporations / Kransman Group – Another destroid manufacturer conglomerate. Designed the Sparta and Spartan. Co-develops the Dehawk and Monster with Viggers/Chrauler. Specializes in MBR robotics.

A manufacturer that jointly developed the HWR-00-Mk.II Monster. The Spartan was also developed by this company. Even though it seems to have originally been an automobile parts manufacturing industry, Centinental also had something to do with the development of the VF-1.

Hughes Corporation – Primary manufacturer of GU (gun unit) weapons for variable fighters.

Raytheon Industrial – This is one of the leading manufacturers of missile technology, sometimes working with Bifors and Erlikon.

Bifors Corporation – Another producer of missile technology.

Erlikon – Another producer of missile technology as well as high-power ballistic weapons for mecha.

Mauler Industries – A company that produces energy weapon technology, including lasers and particle beam cannons.

Ramington – A company that primarily makes mecha ballistic weapons, and some explosive components for missile warheads. Produced the mecha-scale hand grenade used by the VF-1 GPS unit.

Astra Weaponry Incorporated – This group exclusively deals with multi-weapon modules used by various destroid units.

Orguss Manufacturing Conglomerate – This group designed the VF-O-1A Orguss Valkyrie as a heavy combat mecha that combined the roles of the variable fighter and the destroid. Unfortunately the design had inherent flaws and not many units were made.

SDF-1 Onboard Weapon Factory – Not truly a company, the onboard factory produced the Phalanx and Maverick, and made designs for the SPD-1 Stampede.

Macross Consortium – While not truly a company, the Macross Consortium is the UN's own science group, composed mostly of civilian contractors. They have been involved in the development of many different projects, including the virtual idol Sharon Apple.

Macross 7 Science Group – Again, not a true company. Lead by Dr. Gadget Chiba, they devised the sound energy theory and developed the Sound Energy System, Sound Booster, and Sound Buster Cannon technologies.

Macross Galaxy Variable Fighter Development Arsenal (Guld Works) – The Macross Galaxy designed and produced the VF-27 and had extensive research into cybernetics.

L.A.I. – This group has a hand in the Macross Frontier fleet, and funds the S.M.S. group. They developed the VF-25 and VF-29, 3rd generation space fold booster, MDE warheads and anti-Vajra particle beam weapons. It is headed by a macronized Zentraedi named Richard Birla. The S.M.S. originated as a private escort service for his merchant ships, and was around before 2040 (date they received 3 VB-6 units).

An integrated mechanism manufacturer whose location is placed in the Macross Frontier Fleet. The company works with such things as the VF-use EX-Gear G-proof suit and the fold quartz using inertia control system, ISC. L.A.I is bound to the New Unified Forces with a licensing agreement in the armament manufacturing field, and it also performs such things as the specification change and production of every kind of armament. The VF-25, the next version main VF, is due to L.A.I development.

The acronym appears to stand for Luca Angeloni Institute.

Skylab – An emergent interstellar food service enterprise that deals with an extensive range, from biotechnology to family restaurant management. It came up out of a coffee shop on Eden.

Vistula & Oder – A well-established interstellar transportation company whose parent body was an OTEC OTM research public corporation. Vistula & Oder is known strongly in such things as shipbuilding aimed at civilians and the passenger realm. They serve as the primary banking institute onboard the Macross Frontier.

Tachyon & Express – A Zentraedi enterprise whose business was expanded from an express home delivery company by Kwadoran after the First Interstellar War. They have an established reputation in high-speed transport of small-sized cargo.

Witchcraft – This is a restricted medical company on the Macross Galaxy that caters to the Galaxy's military forces. They produce the drug that Sheryl takes to suppress her Type-V infection.

Chapter 7 – Sports & Entertainment

Not all entertainment in the 21st Century is virtual. Many traditional sports remain popular, such as baseball, soccer and basketball. A new sport was developed onboard the Macross 7 fleet; Tornado Crush.

T-Crush (Tornado Crush)

In late 2045, onboard City 7, a new form of sports was created. T-Crush was developed as a "gladiatorial" style sport, combining track racing with hand to hand combat.

In T-Crush, two teams of 11 members, wearing air blades (hover boots) race around a track. Points are earned by the number of runners of the opposite team behind the "A" runner (Ace Runner). Overtaking 10 at a time will double the score to 20, lapping them twice will double the score further. However, the main attraction is really the fighting between the two teams.

Positions:

1 – Ace Runner, typically specializes in sprinting
2 & 3 – Runners, typically specializes in marathon running
4 – Lead Attacker, has the best speed and combat balance
5 & 6 – Attackers, typically the stronger fighters
7 – Lead Blocker, has the best endurance and defense
8-11 – Blockers, typically specializes in grappling or tripping

Rough Play Battle – the opponent is in a suit of armor, which uses the Mind System that causes stun damage, for the purpose of KO'ing the opponent for a 10 count, while the challenger has light armor and air blades. The player can also lose if his air blade batteries die.

<u>The Truth about T-Crush</u>

The cover is that T-Crush is a competitive sport requiring endurance, hand-eye coordination and lightning reflexes. The sport was presented to recruit potential pilots with those traits. In reality, the Zentraedi, even to this day, are having trouble coping with certain human emotions. This Mind System is actually "stealing" emotions from the players by taking spiritia from the players.

The Zentraedi were created to unemotionally fight any opposition that their creators told them to fight. With the culture shock induced by the humans, with great help from Minmei, the Zentraedi's innate emotions were awakened. Because they did not have emotions for so many thousands of years, they don't have the full range of emotions that humans have, or at least they don't recognize them as such. By taking spiritia from T-Crush players – full of excitement, competitive need, and the thrill of victory – the Zentraedi are attempting to get back in touch with their militaristic history, believing the have become "soft" and incapable of fighting an enemy force properly. This spiritia has proved addictive to the Zentraedi.

In March of 2045, Zentraedi blooded Varauta soldiers infiltrated the Macross 7 fleet. In late 2045, with the help of collaborators in the fleet, they present the T-Crush game as a way to collect the desired "type" of spiritia.

Civilian – T-Crush Player

T-Crush players have a good mix of endurance, speed and agility; supposedly traits that make them potential VF pilots.
Skills: Hand-to-Hand or Brawling, Awareness/Notice, Dodge & Evade, Running, Gymnastics, Athletics, Personal Grooming

Blades – Provide a flight speed up to MA 5 (Mekton-scale). The batteries provide 30 minutes of flight time. The air blades can also be used for leap dodging, granting a +5 to their defend roll to dodge. Each use for dodging uses 1 minute of battery power.

G-Wrists are wrist bracers that produce electrical resistance directly to the muscles to make it as if the runner is wearing weights over his whole body. (-3 to all DEX rolls)

Vanquish

In 2051, the racing of restored/overhauled variable fighters became a popular sport, combining precision flight handling with battroid combat. Thus was Vanquish racing born.

Behind the scenes, several large producers of variable fighter technology, including the NUNS, participate in Vanquish racing through proxy racers, to test out the newest technology in "controlled practical combat situations". This is done to gather data for the further development of their fighters, and incidentally falls into "black market" classification.

In 2058, the 7th Vanquish race for the Hoshiten Cup is held onboard the Macross Galaxy's Riviera-class ocean ship.

Civilian - Vanquish Racer

This template is for Vanquish racers who do not come from a military background. Those who are/were military pilots should use their original template.
Skills: Mecha Pilot: VF Series, Mecha Combat, Dodge & Evade, Awareness/Notice, Mecha Weaponry, Endurance, Navigation

Many traditional sports remain popular. Among these are baseball, basketball, pro bike racing and swimming/diving. After Space War I, many macronized Zentraedi picked up interest in sports as an outlet for their need for physical competition. Zentraedi naturally gravitated to boxing and wrestling, and macronized Meltran pro-wrestling gained a great deal of popularity. The Zentraedi also have an underground full-contact competition for macronized warriors known as Su-Dai (while this term originates in Robotech, Macross 7 showed Veffidas and another macronized Zentraedi "street fighter").

Another relatively new (revised) sport is Cosmo Bike Racing. This is much like traditional motorcycle races except it uses hoverbikes in space.

Macronized Meltran Pro Wrestling

Civilian – Pro Sports

This includes all other professional athletes, both micronized and macronized.
Skills: Athletics, Personal Grooming, Awareness/Notice, Endurance, First Aid, Human Perception, choice of Sports, Strength Feat, Gymnastics, Drive or Hand-to-Hand/Wrestling/Martial Arts (pick)

Aside from sports, many other venues of entertainment exist, ranging from traditional to modern. Movies and concerts are still quite popular. Macross DYRL shows a type of holographic amusement where people stand on platforms to have pre-programmed holograms of various clothing displayed over their bodies.

Macross Frontier shows that many Japanese cultural arts are still around, including kabuki, noh, origami and iaido. It also seems that every colony fleet has at least one Chinese restaurant, complete with waitresses in short-skirted Chinese dresses.

Chapter 8 – Colonies and Planets

Earth was nearly annihilated in 2010 by Gorg Boddole Zer's fleet, being reduced to a little over 700,000 people (including survivors on the moon base and orbital colony clusters). UN Spacy implemented a human preservation plan through colonization of nearby planets, launching one or two colonization fleets per year.

All together, there are somewhere between 30 to 100 colonies, and several hundred UN bases spread throughout the galaxy. Each colony or colonial fleet is considered to be an independent sovereign political body under the UN charter, and will have their own local laws in most cases. Ancient ruins, believed to belong to the Protoculture, have been found on 14 planets by 2059.

The Last Transmission from Lynn Minmei, Megaroad-01 Fleet

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URL  minmei l (g)megaroad 1.ga.un/ >>>>> ACCESS COSMONET MAIL NAVIGATOR

To everyone on dear Earth,
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In the sea of stars that dazzles the eye, there's a vast, deep, open jet black hole. A beautiful, yet heartrending enigmatic melody flows from the depths of the dark hole that fills the center of the galaxy. Is this music merely a natural development, or does intelligent life live on the other side of that dark hole? In order to confirm what's causing it, we who boarded the Megaroad, after wavering in the center of the galaxy, have decided to start on a risky journey into unknown space. What really waits in the darkness of this dark hole? Nobody knows if we'll be able to return to this galaxy again.

However, as long as there is "something" there, I think I'll change songs of hope into light, and will willingly go.

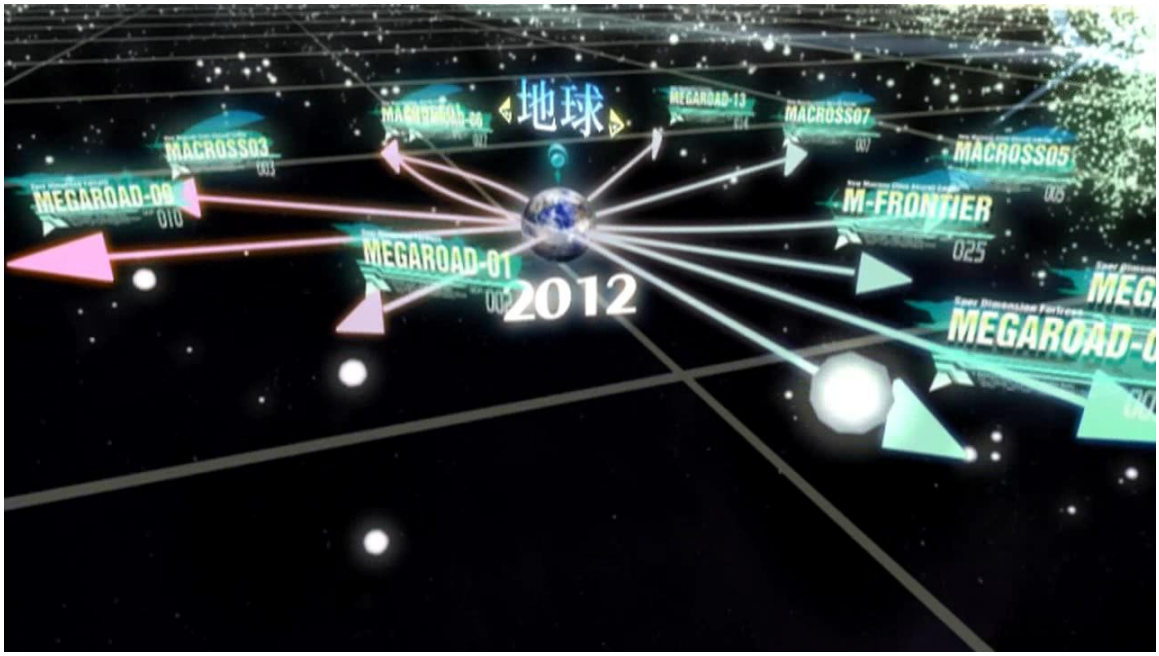
July 7, 2016 AD (Thurs)
With love, from the center of the galaxy,
Lynn Minmei
minmei l (g) 1.ga.un/

Colony Fleet Classifications

Short-Distance Colony Fleet – Megaroad class; used to find colonies within 100 light years of their planet of origin

Long-Distance Colony Fleet – New Macross class; used to find colonies beyond 100 light years of their planet of origin

Super Long-Distance Colony Fleet – Specialized fleets used to find colonies at extreme ranges and near the galactic core (Macross Frontier, Macross Galaxy)



Known Colony Fleets

Megaroad 1 – Commanded by Misa Ichijyo-Hayase, launched in 2012 from earth and reported lost in 2016. No trace of the fleet is ever found, and the loss of the fleet is kept secret from the public for almost four years. Also lost with this fleet are Hikaru and Miku

Ichijyo, Lynn Minmei and Vrlitwhai. The Megaroad 1 mission was to explore and colonize near the galactic core, despite Exsedol's warnings to stay away from that area of the galaxy. Footage in the opening of Macross Frontier clearly shows the Megaroad 1 fleet going rim-ward until 2014, then turning core-ward until 2020-ish, and then turning towards the galactic west. The last letter from Minmei (above) implies they found a wormhole and traveled well beyond communications range, or were destroyed by the galactic core's supermassive black hole.

Megaroad 2 – Launched in 2012 from earth and heads directly galactic east.

Megaroad 4 – Launched in 2012 from earth and colonizes planet Eden later that year.

Megaroad 6 – Launched from earth and heads into the galactic west, deep into what is believed to be the Stellar Republic core systems.

Megaroad 9 – Launched from earth and heads towards the galactic rim.

Megaroad 13 – Launched in 2019 from earth to investigate the planet Rax as a possible colony (see below). The fleet arrives in the Varauta system in 2025 and are subjugated by the barely-aware Gepernich.

Megaroad 24 – Destroyed during construction in May 2029.

Megaroad 25 – Destroyed during construction in May 2029.

Megaroad 28 – Successful colonization in 2034.

Macross 1 – Launched from earth and heads towards the galactic rim in September 2030.

Macross 4 – Colonizes the planet Sephira, 5th planet of the Laramis star system in 2033.

Macross 5 – Launched in 2036 from earth to investigate the Varauta system and to colonize Rax. The fleet arrives in the Varauta system in 2043 and are defeated by the Varauta Empire and then subjugated by the Protodeviln after awakening Gepernich and Gigile. The Macross 5 fleet has a large percentage of Zentraedi colonists (all Zentraedi?). Listed as destroyed in September 2045 along with the planet Rax.

Macross 7 – This is the 37th colonial fleet, launched in 2038 from earth to find a suitable planet near the galactic core despite warnings from their advisor, Exsedol Forma. The fleet encounters the Varauta Empire in 2045, and after the first few battles discovers the truth of their enemy and the fate of the previous fleets. The Protodeviln/Varauta are defeated in 2046. The Macross 7 fleet is commanded by Maximillian Jenius, with Miriya Jenius as City 7's mayor. This fleet has the secondary duty of expanding the Galaxy Network in that region. Last seen active in deep space near Zola in 2047.

Macross 9 – Launched from Eden and heads towards the galactic NE. Location of Macross Generation storyline.

Macross 11 – Launched in 2041 from Eden and heads towards the galactic SE. The Macross 11 fleet is completely English speaking. Home of Fire Bomber American and their manager Lynn Kaifuun, claiming that Fire Bomber stole all of their songs, despite their obviousness as a copycat band. The Macross 11 fleet is mentioned in the radio dramas played on ZZNQK Zolan Radio Network in the M7 Dynamite OVA and shows up in the last episode of Macross Frontier. Last seen active in deep space in 2059.

Macross 13 – Launched in 2043 from Eden and heads towards the galactic NE. Home to British Bomber, a cover band who translated many of Fire Bomber's songs into English and receive a good amount of fame. Later, the flagship is captured by the Black Rainbow terrorist group and modified for an assault on UN main headquarters in 2051 (Battle 13 is destroyed February 14, 2051).

Macross 15 – Launched from Eden and heads towards the galactic core.

Macross 17 – Launched from Eden and heads towards the galactic east.
Macross 19 – Launched from Eden and heads towards the galactic SW.
Macross 20 – Launched from Eden and heads towards the galactic east.
Macross 21 (Macross Galaxy) – Launched from Eden in 2031 as part of the 9th large-scale colonization fleet, and heads towards the galactic core near the Macross Frontier fleet. They have no Zentraedi population. They are the leaders in cybernetic technology by 2059. The fleet is virtually destroyed by the Vajra, with their battle carrier destroyed over the Vajra homeworld by Battle Frontier and Macross Quarter. Listed as destroyed in September 2059 over the Vajra homeworld.
Macross 23 – Launched from Eden and heads rim-ward towards the galactic SW.
Macross 25 (Macross Frontier) – Launched in 2041 from earth as the 25th Macross class colonial fleet, and the 55th super long-distance colonization fleet. Encounters the Vajra near the galactic core and barely makes it to land on the Vajra homeworld. Frontier stands out as having a completely natural environment within the main island ship. Successful emigration to Vajra homeworld in September 2059.

** Yes, according to all of the official Macross information the Macross 21 (Macross Galaxy) launched -before- even the Macross 4, 7, 11, 25 and so forth. The Macross 25 (Macross Frontier) launched the same year as Macross 11.

Colonies and Places of Importance

Many of these colonies and places are only mentioned in passing in the Macross saga, and others are from the various Macross console games. As such, there is minimal information regarding many of them.

Local Group

The local group consists of those colonies and bases within 100 lightyears of Earth. It includes:
Groombridge 1816 Helios [Eden]
Acheron
Avalon
Avemaria
Banipal
Bellfan
Beneb Star System
Cristrania
Dahan
Hydra
Iota
Neo York
New Asia
Salvation
Susia

Beyond the Local Group

102.6 LY; Base Magic Mirror

VF-X2 Mission 4

117.1 LY; Hurtz system
Protoculture Ruins (huge empty cave full of blue Protoculture gack)

128.7 LY; Area ASR8283200
VF-X2 Mission 4

174.7 LY; Hyde City
VF-X2 Mission 2, 6

Earth

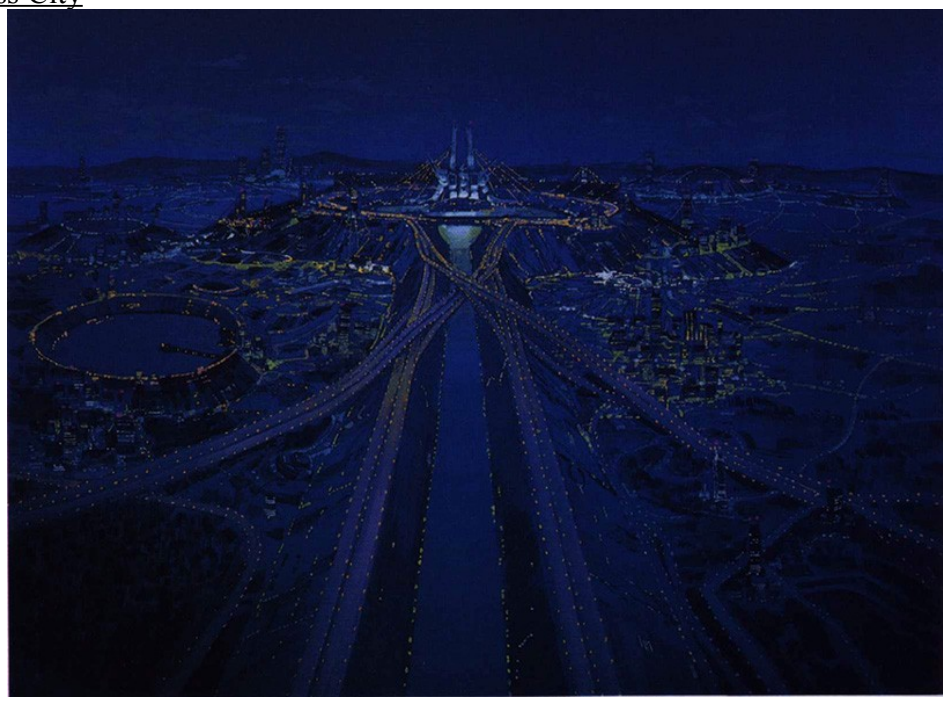
Earth hosts a series of colony clusters in orbit. The planet earth still has some areas that remain inhospitable after the bombardment of the Boddole Zer fleet in 2010.

Macross Plus showed that the earth has a veritable defense grid of killer satellites and capital ships to protect the homeworld of humanity from further invasion fleets. As such, there are approximately 3000 capital ships and over 3000 automated attack satellites surrounding earth (as of 2040), including several rebuilt Zentraedi capital ships armed with heavy particle beam cannons.

Alaska is the location of the main headquarters of the UN, in Macross City where the SDF-1 remains as the central office. The Grand Cannon remains a slag pit.

Eagle Nest Aerial Tactics Center is located on earth as well. Eagle Nest is the most prestigious flight training center, and produces many ace pilots each year. During the late 2030's to early 2040's, ace Meltran pilot Miriya Jenius was the head instructor of this instillation.

<u>Macross City</u>



Construction of the city started in 2010 after the defeat of Boddole Zer, and continued to expand over the next couple decades. At the core of the city is the Macross which sits in Macross Lake (a heavy particle beam cannon crater that filled up with water from the ocean). The old Macross was overhauled in 2012 and left in Storm Attacker configuration for use as the main UN Government headquarters. The city is easily the largest city on earth, and possibly the largest in UN controlled space.

It is from here that all other UN bases on earth are coordinated. Macross City is the hub of all commerce, technology and information on earth.

Mayan

Mayan was where the ancient Protoculture artifact was discovered on the ocean floor near the island in 2008. The people of the island lived a peaceful life free from disease, shame, poverty, or most problems found in large cities. The people themselves are believed to be the most pure-blooded descendants of the original Protoculture colonists that visited earth long ago. The tribe passes down a position of the high priest/priestess who maintains the oral tradition of telling the legends of the “bird man” and protects the island from kadun (spirits of anger and fear).

Mayan is a solitary island in the South Pacific Ocean, near Australia.

South Ataria Island

This was the original island to the south of Japan where the ASS-1 originally landed and was rebuilt. Over the ten years of research and rebuilding of the spacecraft, a large city grew up around the construction site. The entire island and city was left in orbit around Pluto in 2009 when the SDF-1 attempted to space fold while in earth's atmosphere. It sits in the same location as South Iwo Island near Japan in the real world.

Moon

The moon has 2 major military landmarks – the Apollo Base and the Grand Cannon IV. There is also Moon Riverside City located here. The moon also has several shipyards and mecha production facilities.

Also in orbit is the Protoculture automated weapons factory that was captured from the Zentraedi late in 2010. It has been refitted to build VF-11s (and eventually the VF-19), automated weapons satellites and other capital ships. Over the last 4 decades, it has been rebuilt and refitted, and is home to a good portion of macronized Zentraedi workers who are uncomfortable on earth. It is located at the Lunar Lagrange Point.

Venus

The heat, pressure and acidic content of the atmosphere prevents current colonization on the planet itself. Colonists live in orbiting colonies such as Henry Beggs Station.

Mars

The Mars base Sara was eventually rebuilt and is now fully functional again. H.G. Wells City is also located on this planet. Mars remains a largely military industrial colony throughout the saga.

Jupiter

The actual planet cannot support any settlements, however, there are several heavily radiation shielded colony clusters in far orbit around the planet, including White Flora Station, Miranda Station and Brangogne Station. There are also military bases on several of the moons, particularly on Europa 7. Following suit from other sci-fi RPGs, the

Jovian region is likely to be a heavy industrial and mining area with facilities having heavy radiation shielding.

Saturn

As with Jupiter, any settlements are orbiting colonies such as Red Woods Station.

Neptune

Again, orbiting colonies such as Grande Savoie Station.

Pluto

Pluto has no real bases, but has several long distance sensory arrays for early warning of invading fleets. The remains of South Ataria Island remain in orbit and are sometimes visited as a historical site.

Eden

Eden was the first planet outside of the Sol system colonized by humans after Space War I by the Megaroad 4 fleet. The planet was named Eden for the fact it was nearly perfect, having no major deserts or wastelands. Most of the planet is lush plains and forests. Eden is located 11.7 light years from the Solar System in the Groombridge 1816 Star System. Virtual Idol Sharon Apple held her debut concert here in 2040. Eden has 2 small moons.

This colony is home to the New Edwards Test Flight Center, a military testing ground for prototype variable fighters. It is here that the Project Supernova of 2040 was held.

Zola

The planet Zola is a verdant planet in the Vega Quadrant. The northern hemisphere is mostly mountains and barren, rocky wastelands covered with overlapping craters. The southern hemisphere, however, is lush forests and oceans. Zola is an agricultural planet, and the Zolan people are in touch with nature. There is virtually no pollution, and the technology is roughly the equivalent of earth in the 1970's. The planet has no moons, but rather has a crude ring of asteroids around it, being closer to a north to south ring instead of near the equator (approximately 45 degrees tilt from the equator). Zolan architecture appears semi-organic in design, not unlike Zentraedi.

The core of the planet contains a very powerful life energy (possibly a spiritia storage planet), which affects the planet in two ways. One is that the group of galactic whales pass close to the planet every year to draw off some of the energy of the system's sun to continue their migratory cycle across the galaxy. Second is that there is a series of hot springs that tap that energy, healing anyone who bathes in them.

Another interesting feature is the whale graveyard, where every 5,000 years the galactic whales pass by to deposit their dying into the graveyard – which may be what gives the planet its life energy. Those whales who live to 7,000 years of age enter the atmosphere and circle the graveyard to be absorbed into it, restoring the energy reserves and causing new whales to be created. (More information about the galactic whales in the bestiary section.)

Ironically, only a very small handful of Zolans are even aware of either the hot springs or the graveyard. Even after the discovery, the Zolans took great precaution not to commercialize either, so that neither would be defiled nor overrun with tourists.

On the down side, because of the galactic whales, there is a high concentration of bacteria that is lethal to those that aren't immune. Zolans are naturally immune, but any Zentraedi or humans visiting must be immunized (takes about 2-7 hours to take effect). The bacteria causes a high temperature in a victim within 48-72 hours, with accompanying weakness (-2 STR and BOD) and extreme drowsiness and vertigo. After another 72 hours or so, the victim will die unless treated and immunized. Anyone born on the planet is inherently immune. The inoculation itself, an herb called teptramiracine, will also cause the same weakness and vertigo for the same duration, but wears off with no further ill effects.

Zola possesses a full range of animal life that is relatively close to those found on earth, with many seeming to be hybrids of two different earth creatures. The one animal of note are the Zolan snakes. These creatures are passive and friendly with the Zolan people, who typically have one draped around their neck. The Zolan snakes are intelligent and have their own language as well as being able to understand Zolan and can read the ancient Protoculture writing. (More information about them in the bestiary section.) A large amount of the creatures on Zola are marsupials or have pouches for their young; including the avian species.

The Zolan branch of the Galaxy Patrol consists almost exclusively of VF-5000 units, armed with non-lethal weapons. The force does eventually get a single VF-19P in the year 2047.

the galactic whale graveyard

Based on the craters on the planet, it is possible that Zola was assaulted during the war with the Inspection Army. Following the storyline, it is logical that if the Protoculture had the same interference in the Zolan's background as they did with the humans, the Protoculture may have seen Zola as a spiritia storage planet. The Protodeviln no doubt discovered Zola and tried to take the planet for their own. The resulting destruction may have drained the reserves of the time period. This also makes sense for the Zolan people to only be in the technological level they were in by the time they allied with the UN if they had to rebuild their technology. The ring of asteroids orbiting the planet may be the rubble of one or more moons Zola may have possessed 500,000 years ago. The Zolan snake may have been created as messengers or possibly even translators for the Protoculture.

Varauta

The Varauta system is located near the center of the galaxy around a star designated as Alpha 1101, in the Vega Quadrant. It was originally used as a testing ground for the Zentraedi series, and later, the Evil series prototypes. The bulk of the testing was carried out on the first planet of the system, and this is where the sub-dimensional energy beings came through and possessed the Evil series prototypes.

The third planet of the system, named Rax, was set to be colonized by the Megaroad 13 fleet in the late 2020's. At the same time, UN Spacy lost all contact with the fleet. Later, the Macross 5 fleet, containing a large Zentraedi population, went to Rax to colonize it and also to investigate the missing Megaroad 13 fleet, and are also subjugated into the Varauta Empire. Rax is destroyed by Gigile in 2045 when he overcharges his gravimetric field to kill Valgo. The Protodeviln refer to Rax as Planet GGT.

Rax

The fourth planet of the system, officially designated as Varauta 3198XE, is an icy world incapable of supporting most life forms. Constant blizzards and howling winds on a continental scale ravage the planet, making it hostile to all but the most hardy of space travelers – which is most likely why the Protoculture decided to seal the Protodeviln on this planet, deep in a network of tunnels and massive underground caverns.

Varauta 3198XE

Cristriana

This colony planet is home of the New Nile weaponry base, until it was destroyed in 2018. New Nile developed the variable Glaug fighter to replace the old Zentraedi mecha.

New Asia

There are Protoculture ruins on this world, and UN Spacy built a biological weapons base nearby. UN Spacy sent the Dancing Skulls unit to destroy the base in 2022, after it was deemed a biohazard.

Neo York

There is an UN Spacy resupplying base here. This was the testing site of the VF-5000. The Free York Liberation League makes two attempts to capture the VF-5000 prototype in 2020.

Iota

??

Sephira

Sephira is the 5th planet of the Laramis star system. It has around 6 million inhabitants in 2050.

Endebald

Endebald is the 3rd planet of the York star system.

Vulcan

Vulcan is the 3rd planet of the Sharma star system. Vulcan gains an autonomous government in 2040.

Hydra

Site of Hydra civil war.

Salvation

Site of Salvation war.

Avemaria

??

Bellfan

Max and Miriya rescue U.N. Government Chairperson Lawrence Yun Kemal from here in 2030.

Eden 3

Investigation into possible colonization begins in 2042. Environmental modification begins in 2045. Over 90% of the surface is covered with oceans.

Veil

This snowy planet is home to a small mining colony. It is also home to Emiria Jenius, who moved here to practice her singing as a macronized Zentraedi. It supports a small mining town, searching for Barnageum Mineral. Supposedly, this planet was a lush, forested world around 2,000 years ago. The colonists are primarily of Hispanic stock.

During the UN Spacy/Varauta war, Nekkei Basara visited the planet (due to a space fold accident). Through his spiritia powers, seeds that were buried in the ice for ages began to sprout.

Banipal

Coal mining planet. This colony was mentioned in the Macross Plus OAV as a possible place to reassign Isamu Dyson.

Dahan

Max and Miriya battle Zentraedi terrorist group Struggle in orbit over this planet in 2029.

Susia

UN Spacy weapons research base.

Elysium

This colony is in the G-PN 88 area in the Sagittarius Arm of the galaxy. Colonization begins in 2029 and the planet is abandoned in 2041.

Barnard's Star System

Site for planetary fragment disposal. This location was mentioned in the Macross Plus OAV as a possible place to reassign Isamu Dyson.

Gallia 4

Fourth planet of a binary star system. Since the solar revolution cycle corresponds to rotational period, it is divided into day and night-sides. The Gallia binary star system consists of a large main star and a large companion, and thus a strong solar wind blows in the system. Gallia 4 has a single moon.

Colony with minimal atmosphere, and home to the rowdy 33rd Zentraedi marine fleet. They demand a concert from Sheryl Nome in 2059 or they would rebel. The planet is ripped apart by a dimension eater device that dissolves approximately ¼ of the planetary mass.

In 2048 this planet was studied by the 117th large scale research fleet and was attacked by the Vajra and wiped out when Ranka Mei unintentionally drew their attention by singing aimo.

The planet itself hosts large jungle areas full of various animals and even butterflies. Up until 2059, a sizeable Vajra colony was living under the wrecked SDF-04 Global.

Vajra Homeworld

The Vajra homeworld, which becomes the new colony for Macross Frontier fleet in 2059. The planet has least three moons, and an artificial solid ring around it. It is a lush verdant planet with vast oceans. Little other information is known other than it is "close" to the galactic core.

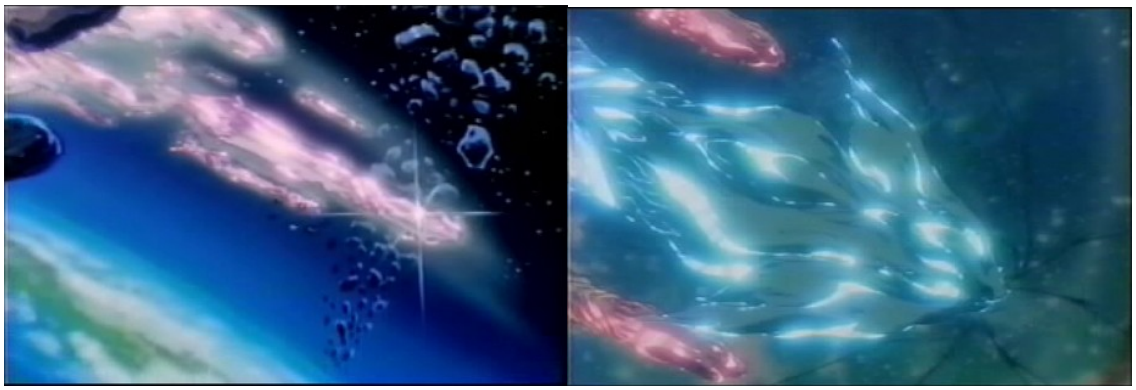
Chapter 9 – Bestiary

This chapter covers some of the more interesting creatures of the Macross saga. Standard earth creatures are not covered here.

Galaxy Whales (Vahla Ena)

The Galactic Whales, officially referred to as the Vahla Ena are massive spacefaring creatures comprised of energy and flesh all in one creature. These creatures are presently being studied by the Galactic Academy on Earth, and from research posts on the planet Zola where they migrate to every year. Pink in color, and glowing with stored energy the galactic whales are capable of not only travel in space at sublight speeds, but are also capable to jump to hyperspace; a feat impossible to any other living creature in the galaxy. Galactic whales appear in many ways to resemble and respond like the whales of Earth, even emitting whale song.

However, for a beast that is over a kilometer long, the whale song of the Vahla Ena can be devastating to the electronics of nearby ships and mecha causing them to short out or even explode, although a pinpoint barrier will shield a mecha or ship from their song. (All mecha and ships within 20 Hexes suffer 1K every round to each servo from the song unless they have an active PPB system.) Furthermore, the song shorts out all combat computers and sensors while in range. They are intelligent and can differentiate between friend and foe; protecting allies from their damaging song.



The planet Zola holds a special significance for the whales as they travel their every year drawing energy from Zola's sun as they leave orbit. Traveling in a large herd with an enormous, even by galactic whale standards, white galactic whale leading the herd the sight is awesome to behold. Little was known as to the reasons behind the Whales traveling to Zola every year until it was discovered that a Whale cemetery exists on the planet where whales that have lived for 7,000 years go to die. Although it would appear that the whales die in a swirl of energy and color the truth is that they are achieving rebirth by giving their energy so that new young Whales are born into the herd. The only whale that doesn't go to the cemetery to die/be reborn, is the white whale which is believed to be millions of years old, and 8 times the size of the other whales, it also is aesthetically different from the others as well.

Sadly the whales are a target for poachers who crave the bodies of the whales to use for starship fuel and for use in fold drives, as they create a smoother and more efficient engine. However, on the flipside the whales have healing properties. As they pass the planet Zola bacteria from the whales enters the atmosphere of Zola. To a non-native of Zola this would be a bad thing if the bacteria got into a wound of some description unless it was properly healed, however near to the whale cemetery the springs and river nearby have minor healing abilities due to the whales bacteria and energy. As the whales are fold capable they can potentially be found anywhere in the galaxy, but the one place they are always guaranteed to be seen is Zola.

Native Home : Space
Size (Length) : 1200 meters
Size (Height) : 100 meters
Numbers : 30+ (travel as part of a herd)
Movement : Sublight & Fold capable
Relevant Stats: Kills 5000, SP 50 (pink); Kills 50,000, SP 100 (great white)

Sonic Aura: The song of the galactic whales inflicts 5K to everything within 500m, even in space (apply this damage to each servo). The great white inflicts 15K to a 2km radius. The great white appears to be able to shield individual targets within its area of effect.

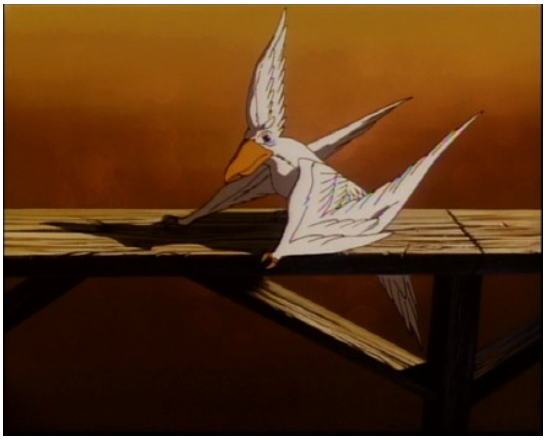
Giant Sauro Bird

Native to Eden, the giant wing Sauro Bird is the larger relative of the more common Sauro bird, which populates the planet akin to the seagulls of Earth. The bird is quite friendly, although reclusive and lives in the jungles of Eden high in the mountains where it nests. Few people have seen this white feathered pterodactyl-like creature.

Native Home : Eden (Colony World)
Size (Wingspan) : 20 meters
Weight : 80-120 kg
Numbers : 1 (rare)
Movement : Flight (air)
Relevant Stats: Hits 120, SP 5

Sauro Bird

The Sauro bird is Eden's equivalent of Earth's seagulls and pigeons. Sauro birds resemble a cross between a feathered pterodactyl and a cockatiel. The Sauro bird is white in color and found commonly around Eden cities docks, Star Hill, and the further inland jungle/swamp regions. It is friendly, but easily startled, however it is not afraid of humans.



Native Home : Eden (Colony World)
Size (Wingspan) : 61cm
Numbers : Flocks of 10 to 100 or so
Movement : Flight (air)
Relevant Stats: Hits 3-5

Gyararashi

The Gyararashi are small creatures roughly the size of a small kitten. They resemble a ball of fur with a long prehensile tail, and small feet, (usually only seen when they are running.) They emit squeeking and chittering sounds akin to mice of Earth. On their home planet, the 5th planet of the Pukirases system they are at the bottom of the

food chain and are preyed upon by large creatures. These animals feed upon the Gyararashi dozens at a time to sate their hunger, as the Gyararashi travel in groups of thousands across the desolate landscape of the planet. The only notable Gyararashi is Guvava, the pet of Mylene Jenius. Her father Max Jenius rescued Guvava from Pukirases 5 in 2036 during a UN Spacy Reconnaissance Mission there. Since Mylene has had Guvava for over 10 years now, it is apparent that the gyararashi have a much longer lifespan than terran rodents.

Gyararashi can form an empathic bond with someone, allowing them to sense and emulate the emotions of the person they share their bond. They also seem to be very spiritia sensitive; Guvava was used a couple times to trace Basara's song.

Native Home : Pukirases System (5th Planet)
Size (Length) : 25-30cm including tail
Numbers : Thousands
Movement : Ground
Relevant Stats: Hits 2-3

Zolan Snakes

Almost all Zolans can be seen to have wrapped around their necks a strange three-eyed snake. These snakes are light tan in color and feature a large central eye, and two regular eyes beneath them. They are intelligent and speak their own language, which most Zolans can understand. They are friendly and are generally asleep around the neck of the Zolan carrying them. Incidentally, these creatures can read and understand the ancient writings on Zola (ancient Protoculture script).

Native Home : Zola
Size (Length) : 1.5 - 2 feet
Numbers : Frequent
Movement : Ground

Relevant Stats: Hits 4-6

Eden Chickens

Native to Eden these chickens are genetically related to and closely resemble Earth chickens, with the most obvious differences being that they have a pair of thick feathers on their heads that resemble horns, and their feathers have color patterns resembling Earth cows. They are however, for all intents and purposes, chickens.

Native Home : Eden
Size (Height) : 1 - 1.5 feet
Numbers : Numerous
Movement : Ground
Relevant Stats: Hits 8-10

Hydra

These beasts don't resemble the multi-headed serpents they are named after. They resemble a blue-furred panther with feathered wings and large fluffy ears. They are predators, but normally shy away from humans. However, they are quite powerful and can trash a car easily when provoked. Younger/smaller hydras are often domesticated and kept as pets similar to cats. They appear to be rather tame unless infected by Type V parasites.

Native Home : Eden
Size (Height) : ? (appear to be the size of large lions)
Numbers : assumed to form feline packs
Movement : Ground/Air
Relevant Stats: STR 14, BOD 12, AGIL 10, INT 1, Hits 30, SP 4, Bite 1d6, Claws 1d8, Hits 120, SP 6

Chapter 10 – The Vajra

A bio-mechanical race whose existence had been kept secret by the New U.N. Spacy. These creatures began to be encountered near the central core of the Milky Way Galaxy in 2040, and again, roughly 8 years later by the 117th Long Distance Research Fleet on Gallia 4. The species can survive in the vacuum of space and grows through various stages of metamorphosis. Most of the evolved states appear to have large insect-like bodies (with exoskeletons) with the warrior-types growing as large as human mecha. The Vajra can produce destructive super-dimension energy which can overwhelm Human/Zentraedi starships and their N.U.N.S. variable fighter forces.

In the early part of the television series, Vajra drones (roughly small-mecha sized) are difficult to destroy due to their thick hides as well as their powerful super-dimension weapons which shattered a number of the New Macross Fleet's large warships. Only the latest New UN Spacy equipment, such as the new VF-25 Messiah variable fighters, are able to fend off the increasing attacks by an enemy that is later revealed as being able to adapt to every encounter. They appear to thrive in hives, such as in asteroid fields as well as on planets.

The Vajra have a connection with the V-Type microorganisms which was first seen as a fatal brain disease. 117th Large Scale Research Fleet scientists were known to be researching this virus at time of its disappearance. Only one member of research team survived, Grace O'Connor, who later joined the Macross Galaxy Colony Fleet.

Later episodes showed that the Vajra have Queens which act as thinking/guiding intelligences for their race, themselves linked to their children through special crystals (fold quartz) found in Vajra drones.

The final episodes have revealed that the Vajra communicate using a fold network activated by the fold quartz in the V-Type microorganisms that they carry inside the organs of their body. While each creature is of an elementary (simple) mind by itself, the whole race's fold communication network creates a large collective consciousness that has an advanced level of intelligence. This collective mind is coordinated by a single Queen.

It is learned that the Vajra collective live on an Earth-type world near the center of the galaxy. The planet has three moons and a large artificial ring which encircles its equator with a spiral emblem on its main superstructure. The planet is defended by a large Vajra war fleet which hides in super-dimension space. This world seems to be related to the Protoculture, which was a civilization that created all humanoid life in the galaxy.

It was also explained that the Vajra produce the mysterious fold quartz using interstellar matter and raw materials from fixed stars. This fold quartz allows the maintenance of a real-time intergalactic communication system which allows the collective mind of the Vajra coordinate drones as one entity who act as the collective's body.

The Vajra possess the ability to adapt themselves to new threats. As all Vajra are linked by the race's fold communication network, information is instantly shared across the species, even at the moment an individual Vajra is killed. Through this the Vajra can eventually develop defenses to any enemy weapons that it constantly faces. This is evidenced by the Vajra becoming immune to N.U.N.S reactive weapons of which the N.U.N.S repeatedly deployed in their battles against the Vajra.

It is explained in end of the series that the original Protoculture knew of the Vajra and that they feared, adored and deified their power to the extent of imitating its form, Protoculture technology being an example of this with their Space fold devices, Super-Dimension weaponry and the "Birdman" mecha from Macross Zero, which itself resembles a Vajra Queen.

The Vajra are considered collectively as a Super Dimensional Life Form due to their ability to travel through Super-Dimension space. It was speculated in the series finale that they had been living for hundreds of thousands, if not of millions of years. The Vajra Queen, a super giant life form and main node of their intergalactic hyperspace communication-link (real-time), actively sought out other Vajra life forms to cross breed by using the song "Aimo", which was a Vajra love song according to Ranshe Mei. Humanoid alien races were the first independent-individual thinking races the Vajra encountered and since first contact could not understand how to communicate with them. The Queen had actively sought out humans like Ranka Lee whom were able to communicate via fold waves and tried to rescue them as part of their cross breeding mentality. It was through Sheryl Nome and Ranka Lee's songs that the Vajra finally understood the truth of humanoid method of communication and the nature of individuality.

The V-Type infection was revealed to be part of the Vajra method of communicating but it ended up being fatal in most humanoid life forms except for Ranka

Lee, who was infected in-utero causing the Vajra infection to settle in her abdominal area where it would not be fatal for her.

Grace O'Connor briefly compromised the Queen, taking over her physical body and overriding the Vajra fold communication network. However, after recovering Ranka Lee, both hers and Sheryl Nome's singing connected to the Vajra communication network freed the Vajra and allied them to Macross Frontier to rescue the Queen and put an end to Grace O'Connor's dreams of galactic domination at cost of the Vajra race existence.

The Vajra Queen and her race are finally seen leaving their home world for parts unknown. Only Ranka's pet Ai-Kun remained with her. Her pet does appear to have its own elementary mind thus suggesting that drones have some degree of individual intelligence that contributes to the overall intelligence of the Vajra hivemind.

Type-V Infection

In the intestinal tract of the Vajra exists a microorganism parasite that produces and enhances fold waves for super long-distance communication in near real-time. To the Vajra, this is natural. Unfortunately, this “virus” does not mesh well with humans and their cousins. Because the infection is spread via the blood and fluids of a Vajra, there has been minimal human contamination.

Once a human is infected, the virus gestates in the subject’s intestinal tract. In time, the virus moves to the brain of the subject, and becomes untreatable and lethal at this point. As a side effect, once the disease enters the brain, the subject can transmit and receive space fold waves as the Vajra do.

The Type-V infection is capable of infecting non-humanoid life as well, causing such animals as hydras to become “rabid” and attack people with no regard to their own safety.

Fold Quartz & Hive Mind

In the body of every Vajra is a 2cm x 0.5cm (approximate) shard of purple crystal called fold quartz. This material allows for near-instantaneous communication across the galaxy, which gives the Vajra their hive mind. When killed, this crystal may be removed and used by other races, such as in Sheryl Nome’s earrings.

This fold quartz links the minds of all Vajra to their queen in a massive neural network. Through this network, the queen's intellect guides the lesser Vajra. While the individual Vajra possess virtually no brain capacity (INT 1 or less), the neural network provides them with effectively INT 4.

Adaptation

By use of their hive mind via fold quartz, the Vajra have the ability to adapt to hostile environmental conditions and even damage. Every time a Vajra is damaged by a weapon but not killed (at least 1 damage gets past their armor), there is a chance they transmit that information to the entire swarm. If the Vajra is killed outright, do not roll this chance. Roll 1d10; on a 1-9 the Vajra did not adapt to that attack, but on a 10 it transmits that information to the swarm. If this happens, the entire swarm becomes immune to that attack form in 2d10 rounds.

This does not apply to green type larva or juvenile forms, as they do not have the hardened carapace.

Mecha-like Qualities

Vajra shells are composed of materials almost identical to the UN energy converting armor. They can also generate missile and ballistic ammunition internally. Vajra are also capable of initiating space fold individually. All Vajra of Mekton scale or larger are considered to be regenerating techno-organic units (servos regenerate 1K per round, armor regenerates 1K per day, -1 to all rolls for each system other than armor that is destroyed, +1 MV and regenerate 10% of their ammunition every 5 minutes).

Aimo

The Vajra possessed a single song, a love song, that they sang to attract mates. The song itself has words, and may or may not be in the language of the Protoculture. [Macross Frontier movie rewrites this to a song that Mao Nome discovers, presumably in Protoculture language with some Japanese to fill in missing lines]

Vajra Stats

Green Type Larva

This is the starting point of all Vajra, presumably Stage 1. It is roughly the size of a housecat, having a long tail and six small legs.

Stats: INT 1, COOL 3, PRE 2, EMP 2, AGIL 4, TECH 0, STR 1, BOD 2, ATTR 3, MA 5, EDU 0, LUCK 3
Secondary: END 20, HUM --, Run 15m, Leap 1.25m, Anime Leap 7.5m, Swim 5m, BTM -0, REC 3, RES 9, STUN 10, HITS 20, Lift 2 kg, Throw ?m, DMG ?, EV ?.
Skills: Awareness/Notice 3, Dodge & Evade 4, Navigation 3

Green Type Juvenile

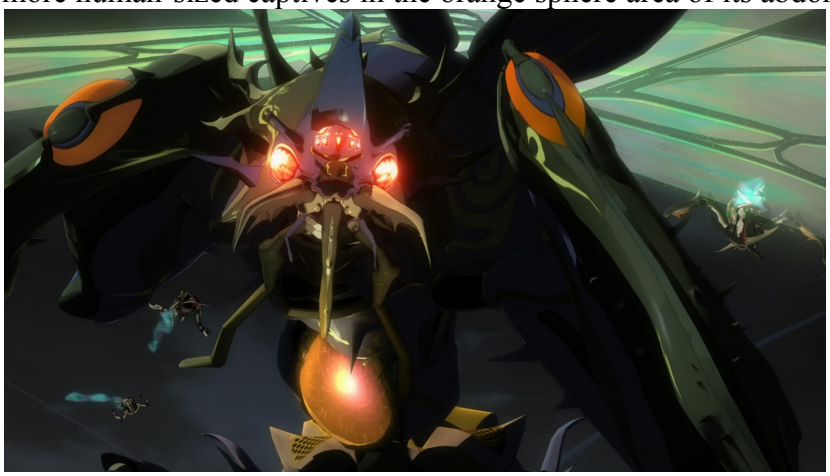
Referred to as "dandiform" Vajra or Stage 2. This is the adult green type.

Stats: INT 1, COOL 3, PRE 2, EMP 2, AGIL 5, TECH 0, STR 3, BOD 4, ATTR 2, MA 6, EDU 0, LUCK 3
Secondary: END ?, HUM ?, Run ?m, Leap ?m, Anime Leap ?m, Swim ?m, BTM ?, REC ?, RES ?, STUN ?, HITS ? (?), Lift ? kg, Throw ?m, DMG ?, EV ?.

Skills: Awareness/Notice 3, Dodge & Evade 4, Navigation 4

Green Type Adult

Adult green type. It seems to be used primarily as a "harvester" unit since it can carry one or more human-sized captives in the orange sphere area of its abdomen.



Stats: INT 1, AGIL 6, STR 14 (mecha), LUCK 5
Skills: Melee 6, Dodge & Evade 6, Awareness/Notice 7
Kills: Head 3K, Torso 8K, Arms (x2) 5K, Legs (x2) 5K, Wings (x4) 2K
Armor: Body/Head/Arms/Legs 4K SP 4, Wings 2K SP2
MA: 100
Weapons:
Scything Blades: +0 WA, 4K, AP, 4 Kills
Other: Has equivalent of SW-AG armor, granting +1 SP as long as the armor is not depleted.

Yellow Type

This is the standard combat type, and most likely the most common.

Stats: INT 1, AGIL 7, STR ?? (mecha), LUCK 5
Skills: Melee 6, Dodge & Evade 6, Awareness/Notice 7
Kills: Head 4K, Torso 6K, Arms (x2) 3K, Tail 2K
Armor: Body/Head/Arms 4K SP 4, Tail 2K SP2
MA: 100
Weapons:
Other: Has equivalent of SW-AG armor, granting +1 SP as long as the armor is not depleted.

Red Type

Heavy combat type, larger than a VF-25 in full armor. It mounts a heavy cannon capable of firing variable output beams.

Stats: INT ?, COOL ?, PRE ?, EMP ?, AGIL ?, TECH ?, STR ?, BOD ?, ATTR ?, MA ?, EDU ?, LUCK ?
Skills: Melee 6, Dodge & Evade 6, Awareness/Notice 7
Secondary: END ?, HUM ?, Run ?m, Leap ?m, Anime Leap ?m, Swim ?m, BTM ?, REC ?, RES ?, STUN ?, HITS ? (?), Lift ? kg, Throw ?m, DMG ?, EV ?.
Skills: Melee 6, Dodge & Evade 6, Awareness/Notice 7, Ranged Weapons 5
Kills: Head 3K, Torso 14K, Arms (x2) 4K, Legs (x4) 8K, Retractable Wings (x4) 2K
Armor: Body/Head/Legs 5K SP 5, Arms 4K SP 4, Wings 2K SP2
MA: 84
Weapons:

Claws: +0 WA, 5K (includes bonuses)
MG: +1 WA, Range 24, 2K, BV3, AP, All-Purpose, 2 Kills, Clip 50
Beam Cannon: +1 WA, Range 1200, 15K, Warmup 1, 15 Kills

Other: Has equivalent of SW-AG armor, granting +1 SP as long as the armor is not depleted.

Red Type II

??

Stats: INT ?, COOL ?, PRE ?, EMP ?, AGIL ?, TECH ?, STR ?, BOD ?, ATTR ?, MA ?, EDU ?, LUCK ?
Skills: Melee 6, Dodge & Evade 6, Awareness/Notice 7
Kills: Head 3K, Torso 14K, Arms (x2) 4K, Legs (x2) 4K, Wings (x4) 2K
Armor: Body/Head/Arms/Legs 4K SP 4, Wings 2K SP2
MA:
Weapons:

?

Other: Has equivalent of SW-AG armor, granting +1 SP as long as the armor is not depleted.

Sub-Queen Type

The sub-queen represents the smaller command Vajra that control fleets.

Stats: INT ?, COOL ?, PRE ?, EMP ?, AGIL ?, TECH ?, STR ?, BOD ?, ATTR ?, MA ?, EDU ?, LUCK ?
Skills: Melee 6, Dodge & Evade 6, Awareness/Notice 7
Kills: Head 3K, Torso 14K, Arms (x2) 4K, Legs (x2) 4K, Wings (x4) 2K
Armor: Body/Head/Arms/Legs 4K SP 4, Wings 2K SP2
MA:
Weapons: Scything Blades (+0 WA, 4K, AP, 4 Kills)
Other: Has equivalent of SW-AG armor, granting +1 SP as long as the armor is not depleted.

Queen Type

The queen is the "ruler" of the entire planet of Vajra. It is she who the Macross Galaxy attempts to take control of to gain power over the Vajra and their galactic neural network.

Stats: INT ?, COOL ?, PRE ?, EMP ?, AGIL ?, TECH ?, STR ?, BOD ?, ATTR ?, MA ?, EDU ?, LUCK ?
Skills: Melee 6, Dodge & Evade 6, Awareness/Notice 7
Kills: Head 3K, Torso 14K, Arms (x2) 4K, Legs (x2) 4K, Wings (x4) 2K
Armor: Body/Head/Arms/Legs 4K SP 4, Wings 2K SP2
MA:
Weapons: Scything Blades (+0 WA, 4K, AP, 4 Kills)
Other: Has equivalent of SW-AG armor, granting +1 SP as long as the armor is not depleted.

Chapter 11 – Galactic Hazards & Living in Space

Traveling and living in space presents some unique challenges and hazards that should be addressed (aside from rogue Zentraedi fleets and bizarre alien lifeforms, that is).

Fold Sickness

Fold sickness is similar to jetlag. The process of entering and exiting space fold can cause disruptions to the sensitive functions of the human body, resulting in nausea, vertigo and fatigue.

Most people aren't affected by fold sickness. Those who are can take a 5 point Vulnerability flaw. Fold sickness imposes a -3 penalty to all rolls, and they cannot move more than half their MA per round without suffering vertigo and vomiting. These penalties vanish after the character rests for [10 - BOD] hours. Pure-blooded Zentraedi are not affected by fold sickness.

Weightlessness

Long periods of weightlessness occur in a spaceship outside a planet's atmosphere, provided no propulsion is applied and the ship is not rotating. This is the case when orbiting the earth (except when rockets fire for orbital maneuvers), but not during atmospheric re-entry. Weightlessness does not occur in a rocket ship that is accelerating by firing its rockets. Even if the rocket accelerates uniformly, the force is applied to the back end of the rocket by the escaping gas and that force is transferred throughout the ship via pressure or tension, precluding weightlessness. Weightlessness in a spaceship or space station is achieved by free-fall. The ship and all things in it are literally falling toward the Earth's surface, but their speed in orbit around the Earth allows for almost perpetual falling.

The myth that satellites remain in orbit because they have "escaped Earth's gravity" is perpetuated further (and falsely) by almost universal use of the zingy but physically nonsensical phrase "zero gravity" (and its tech-weenie cousin, "microgravity") to describe the free-falling conditions aboard orbiting space vehicles. Of course, this isn't true; gravity still exists in space. It keeps satellites from flying straight off into interstellar emptiness. What's missing is "weight"; the resistance of gravitational attraction by an anchored structure or a counterforce. Satellites stay in space because of their tremendous horizontal speed, which allows them (while being unavoidably pulled toward Earth by gravity) to fall "over the horizon." The ground's curved withdrawal along the Earth's round surface offsets the satellites' fall toward the ground. Speed, not position or lack of gravity, keeps satellites up, and the failure to understand this fundamental concept means that many other things people "know" just isn't so.

Space Adaptation Syndrome

The most common initial condition experienced by humans after the first couple of hours or so of weightlessness is known as space adaptation syndrome or SAS, commonly referred to as space sickness. The symptoms include general queasiness, nausea, vertigo, headaches, lethargy, vomiting, and an overall malaise. Roughly 45% of all people to experience free floating under zero gravity have also suffered from this condition. The duration of space sickness varies, but in no case has it lasted more than 72 hours.

On your first trip into outer space (within the first 3 hours), roll 1d10. If the result is 1-2 on your first flight you are permanently immune to SAS, otherwise you just don't get it this trip. On a 3 you are slightly queasy for 1d10 hours [-1 to all rolls]. On a 4-9 you suffer SAS for 1d6/3 + half your roll in days (3.3 to 6.5 days) [-3 to all rolls]. On a 10 you will never fully recover from SAS until you are back in a 1G environment or subjected to a centrifuge or similar method of coping. If you were born in space you get a -4 modifier. If you got SAS on your first flight, you have a +1 modifier (you tend to get it again). If you didn't get SAS on your first flight, you have a -1 modifier (you tend not to get it if you didn't before).

Deterioration

The most significant adverse effects of long-term weightlessness are muscle atrophy and deterioration of the skeleton, or spaceflight osteopenia; these effects can be minimized through a regimen of exercise. Other significant effects include fluid redistribution, a slowing of the cardiovascular system, decreased production of red blood cells, balance disorders, and a weakening of the immune system. Lesser symptoms include loss of body mass (the body gets rid of "excess" blood, leading to dehydration), nasal congestion, sleep disturbance, excess flatulence, and puffiness of the face. The body can grow up to 5cm taller in height.

In practical terms, characters will lose one rank of BOD for the first two months, no loss on the third, one rank on the fourth, sixth, ninth, etc (increases by one month per interval). As all UN capital ships have artificial gravity, and most EVA work doesn't exceed a day in length, this is usually not a concern.

There are five major ways to combat this deterioration.

1) Drugs such as calcium tabs, water retention aids and vascoconstrictors (to raise blood pressure) can help for a short time but lose effectiveness and can lead to additions.
2) Exercise with devices and restraints to simulate a proper 1.0G environment. The amount needed to combat the deterioration varies depending on the amount of gravity; in weightless environments four hours per day is needed, on the moon two hours per day, and on a Mars-sized planet 1 hour per day. Note that strenuous activity such as combat or chasing someone counts as exercise.
3) Centrifuges. This includes rotating tables up to rotating habitation blocks. In smaller environments this can lead to nausea and vertigo.
4) Clothing with elastic or other devices to force the muscles to work to counteract the pressure.
5) Cybernetics and biotech. Augmentation or replacement of atrophied body parts can restore lost muscle/bone mass. Or you can just replace things beforehand and not go through the problem to begin with.

Return to Gravity

Returning to a 1G environment doesn't just magically fix things. Typically a person will require one month per month of weightlessness to adapt back to gravity (half this if they maintained a proper exercise regimen while weightless). Lost fluids are replaced in about a week and lost muscle mass within 1-2 months, regardless of the duration of weightlessness. Bone loss is harder to replace; a person will recover one rank of BOD every 1d3 weeks, although one rank of BOD is permanently lost for every year of weightlessness.

Example: Mike was stationed on a small space station with no artificial gravity for a year. When he first set foot on the station he had BOD 9. The labor was not very taxing, and he wasn't smart enough to remember exercising every day. At the end of the first month his BOD drops to 8; end of the fourth month it drops to 7; after six months it drops to 6; and at the end of the ninth month it drops to 5. He returns to Earth at the end of the 12th month. It will take him between 12 to 64 days to recover his BOD stat, although it is permanently reduced to 8.

Decompression

This is a particular nightmare of any spacer. Fortunately the capital ships and mecha of Macross are constructed of hyper carbon alloy, which isn't penetrated by most handgun weapons (all firearms are still highly restricted in space). However there are plenty of overtechnology-based beam weapons that can rip holes in hulls. Now, in pre-OT vessels such as the antiquated space shuttle, even a 9mm handgun is a scary thing.

As a general rule, for every 2 points of damage that penetrate, a 2cm diameter hole is opened up. Every 2cm diameter of a hole will vent out 6m^3 of air per turn. For example, an 8cm diameter hole will vent 24m^3 of air per turn (4x6m).

How much air is in a typical habitat? Assume the following formula as a guideline: 3.14 x length x (radius squared). This volume is typically written on the hull on the inside and outside of every hatch, mecha bay and window. For example, a 30m cylinder with a 10m diameter has 9,420m^3 of air.

Pressure is necessary for people to live. The fluids inside a person's body are equalized to the pressure of the fluids (gasses such as the air we breathe are fluids). When the pressure outside the body drops, it causes their blood to boil all of the nitrogen out. When pressure is lost, people must make checks at ½, ¼ and 0 pressure.

Half Pressure: At ½ pressure, air becomes thin and hard to breath. Characters must roll BOD +1d10 at DV 15 each round or pass out until pressure is restores.

Quarter Pressure: At ¼ pressure, the oxygen in the area is less than is required to remain conscious. Characters must roll BOD +1d10 at DV 25 each round or pass out. After three minutes in such low pressure, the character loses 1 rank of INT and an additional rank every three minutes thereafter due to hypoxia-induced brain damage. When pressure is restored, all but 1d6/2 (round down) INT can be restored with proper therapy. Furthermore, characters suffer 1d3 damage from "the bends" as nitrogen boils out of their blood per round until the area reaches zero pressure. Once pressure is restored, characters have their BOD permanently reduced by 1d3. (Note that in a helium/oxygen atmosphere characters do not suffer damage from the bends.)

Zero Pressure: At zero pressure, there is no oxygen left. If a character is still conscious, he has 5d6 seconds to remain conscious to watch his life flash before his eyes. They suffer 1d6 damage per turn as the last bits of nitrogen burn out of their blood, and an additional 1d6 INT loss per turn as their brain cells die off en masse. After 1d10 turns at 0 INT, the character is dead with a capital D and their player should start making a new character. At this point, their organs are no longer viable for transplant as most of them have ruptured.

Radiation

Stars put out a lot of radiation; so do gas giants and thermonuclear reactors and reaction weapons. Radiation causes mutation of healthy cells or even causes them to necrotize. There are two primary forms of radiation: electromagnetic and particle.

* Electromagnetic radiation includes thermal/infrared, radio, microwave and visible light (non-ionizing); and ultraviolet, X-ray and gamma (ionizing). Ionizing radiation is more dangerous to life than non-ionizing.

* Particle radiation includes alpha and beta radiation, and neutron radiation. This is energy in the form of moving particles.

Visible Light

Visible light in itself is usually not a hazard. Particularly intense light can cause eye damage and blindness. Transparent visors in mecha and capital ships are polarized to protect crew from blindness from all but the most intense light sources, such as being too close to a star; in which case blindness is the least of their worries.

Light amplified to a certain degree becomes a laser and is capable of cutting through even hyper carbon alloy or penetrating energy shields.

Radio

Radio is used for communication without wires. Radio ranges from 3 Hz (extremely low frequency) to 300 GHz (extremely high frequency). For reference, FM radio is 30-300 MHz while modern AEGIS radar is 3-30 GHz.

As far as I know, radio has no real direct hazard. Some gas giants and some types of stars (pulsars, quasars) and radio galaxies emit natural radio waves. They don't form anything coherent, but could cause interference with radio communications or cause false readings on some instruments.

Thermal / Infrared

Thermal radiation is heat transference, such as from a household radiator or electric heater, and the light from an incandescent light bulb. The obvious immediate hazard from thermal radiation is overheating and being cooked.

Microwave

This includes electromagnetic waves with frequencies ranging from 300 MHz to 300 GHz. As the name implies, microwaves have wavelengths in the micrometer range. It is used in telephone communications, radar, wireless LAN, cable TV and global positioning systems.

Most households are familiar with another application. A microwave oven passes (non-ionizing) microwave radiation (at a frequency near 2.45 GHz) through food, causing dielectric heating by absorption of energy in the water, fats and sugar contained in the food. Microwave emissions of sufficient strength will have a similar effect on people.

Ultraviolet

Ultraviolet is of a wavelength shorter than visible light at the violet end, but longer than that of soft X-rays. UV radiation is well known for causing suntans, and if exposed too long, sunburns. UV also provides "black light", which is at the soft near ultraviolet range with little visible light (UVA range; safe). Another common use is ultraviolet germicidal irradiation (UGI), which uses UVC range ultraviolet radiation that is very harmful to micro-organisms. UGI is used to purify water of molds, viruses and bacteria. UVB radiation contact on skin causes the production of vitamin D, but increases the chances of skin cancer by causing DNA components to bond to each other instead of their opposite pairs.

Luckily, earth's atmosphere blocks most ultraviolet radiation (98.7% of UV radiation is UVA). The catch-22 of UV is that humans need *some* UV, but too much can cause sickness and death.

X-Ray

X-rays have wavelengths of 10 to 0.01 nm and frequencies of 30 PHz to 30 EHz (petahertz 10^{15} to exahertz 10^{18}). X-rays are basically created by accelerating electrons hitting metal atoms. They are also created by some types of compact stars, particularly pulsars. X-rays are used extensively in medical scans as they can detect broken bones, cancer and tumors. In large quantities, X-rays can cause cancer. They are blocked by lead and other similarly dense metals.

Extreme levels, such as the "beam" from a pulsar, can cause mass ionization of an atmosphere and superheat a planet to cause planetary extinction.

Gamma

Gamma rays (denoted as γ) are a form of electromagnetic radiation or light emission of frequencies produced by sub-atomic particle interactions, such as electron-positron annihilation or radioactive decay. Gamma rays are generally characterized as electromagnetic radiation having the highest frequency and energy, and also the shortest wavelength, within the electromagnetic spectrum, i.e. high energy photons. Due to their high energy content, they can cause serious damage when absorbed by living cells. Gamma radiation is used to irradiate medical equipment to sterilize it of all microorganisms.

Gamma rays can be blocked by mass with high atomic counts, such as gold and lead. For example, gamma rays that require 1 cm (0.4 inches) of lead to reduce their intensity by 50% will also have their intensity reduced in half by 6 cm (2½ inches) of concrete or 9 cm (3½ inches) of packed dirt.

The natural outdoor exposure in Great Britain is in the range 20-40 nSv/h. Natural exposure to gamma rays is about 1 to 2 mSv a year, and the average total amount of radiation received in one year per inhabitant in the USA is 3.6 mSv. By comparison, the radiation dose from chest radiography is a fraction of the annual naturally occurring background radiation dose, and the dose from fluoroscopy of the stomach is, at most, 0.05 Sv on the skin of the back. For acute full-body equivalent dose, 1 Sv causes slight blood changes, 2-5 Sv causes nausea, hair loss, hemorrhaging and will cause death in many cases. More than 3 Sv will lead to death in less than two months in more than 80 percent of cases, and much over 4 Sv usually causes death (see Sievert). For low dose exposure, for example among nuclear workers, who receive an average radiation dose of 19 mSv, the risk of dying from cancer (excluding leukemia) increases by 2 percent. For a dose of 100 mSv, that risk increase is at 10 percent. By comparison, it was 32 percent for the Atom Bomb survivors.

Alpha

Alpha decay is a type of radioactive decay in which an atomic nucleus emits an alpha particle (two protons and two neutrons bound together into a particle identical to a helium nucleus) and transforms (or 'decays') into an atom with a mass number 4 less and atomic number 2 less. An alpha particle is the same as a helium-4 nucleus, and both mass number and atomic number are the same. Alpha decay is a form of nuclear fission where the parent atom splits into two daughter products. Alpha decay is fundamentally a quantum tunneling process. Unlike beta decay, alpha decay is governed by the strong nuclear force.

In general, external alpha radiation is not harmful since alpha particles are effectively shielded by a few centimeters of air, a piece of paper, or the thin layer of dead skin cells. Even touching an alpha source is usually not harmful, though many alpha sources also are accompanied by beta-emitting radiodaughters, and alpha emission is also accompanied by gamma photon emission. If substances emitting alpha particles are ingested, inhaled, injected or introduced through the skin, then it could result in a measurable dose.

The largest natural contributor to public radiation dose is radon, a naturally occurring, radioactive gas found in soil and rock. If the gas is inhaled, some of the radon particles may attach to the inner lining of the lung. These particles continue to decay, emitting alpha particles which can damage cells in the lung tissue. The death of Marie

Curie at age 66 from leukemia was likely caused by prolonged exposure to high doses of ionizing radiation. Curie worked extensively with Radium, which decays into Radon, along with other radioactive materials that emit beta and gamma rays.

Beta

In nuclear physics, beta decay is a type of radioactive decay in which a beta particle (an electron or a positron) is emitted. In the case of electron emission, it is referred to as "beta minus" (β^-), while in the case of a positron emission as "beta plus" (β^+). Beta particles move at a speed of 180,000 km/s, around 0.6c.

Beta radiation, composed of electrons, can be stopped by a thin sheet of aluminum. Beta particles are used to treat eye and bone cancer, and as tracers. Strontium-90 is typically used to produce beta particles for these uses. Like many other radiation types, it can cause mutations in DNA.

Neutron

Neutrons may be emitted during either spontaneous or induced nuclear fission, nuclear fusion processes, very high energy reactions such as in the Spallation Neutron Source and in cosmic ray interactions, or from other nuclear reactions such as the historically significant (α, n) reaction. Neutron radiation was discovered as a result of observing a beryllium nucleus reacting with an alpha particle thus transforming into a carbon nucleus and emitting a neutron, Be(α, n)C.

Neutron radiation protection relies on radiation shielding. In comparison with conventional ionizing radiation based on photons or charged particles, neutrons are repeatedly bounced and slowed (absorbed) by light nuclei, so a large mass of hydrogen-rich material is needed. The most effective materials are eg. water, polyethylene, paraffin wax, or concrete, where a considerable amount of water molecules is chemically bound to the cement. Neutrons also degrade materials; intense bombardment with neutrons creates dislocations in the materials, leading to embrittlement of metals and other materials, and to swelling of some of them. This poses a problem for nuclear reactor vessels, and significantly limits their lifetime (which can be somewhat prolonged by controlled annealing of the vessel, reducing the number of the built-up dislocations).

Cosmogenic neutrons, neutrons produced from cosmic radiation in the earth's atmosphere or surface, and those produced in particle accelerators can be significantly higher energy than those encountered in reactors. Most of them activate a nucleus before reaching the ground; a few react with nuclei in the air. The reactions with Nitrogen 14 lead to the formation of Carbon 14, widely used in radiocarbon dating.

-Radiation Simplified-

Protection against radiation

Hardware can be “hardened” against radiation. Microchips can be manufactured on insulating substrates such as silicone oxide (SOI) and silicone on sapphire (SOS), and further shielded with lead or other radiation blocking materials such as boron-10. SRAM resists radiation better than capacitor-based DRAM even though SRAM is larger and more expensive. Software can use redundant elements and error correcting memory.

Planets with proper ozone layers largely shield against cosmic radiation (see below). Heavily shielded colony structures on planets without such ozone also protect at

this level. The magnetic shields of most large-scale capital ships will provide similar protection as a shielded colony.

Smaller spacecraft, including Mekton-scale mecha, have very thin armor for a reason. When cosmic radiation, particularly alpha radiation, passes through metal, the damage is negligible. If the radiation only passes partially through the material, the radiation breaks down into nastier secondary radiation (see ionizing radiation above). So it is best to either block it completely or to let it pass through relatively harmlessly.

Being Irradiated

Radiation is measured in rads, although doses are usually measured in milirads ($1/1000^{th}$ of a rad). A typical human can withstand up to 50 rads of radiation before serious damage occurs. This value is over the person's lifetime. A person on Earth absorbs around 250 milirads of cosmic radiation per year, meaning he would live to be 200 years old before reaching his 50 rad limit (50,000 milirads).

Cosmic Radiation

This covers most of the above list. The hulls of most fighters and spacesuits do not provide sufficient protection against cosmic radiation while in outer space, and such exposure accumulates 1d6 milirads per hour.

Nuclear Reactors

Nuclear powerplants, exposed nuclear waste or cracked reaction warhead casings can subject a person to deadly radiation. Such exposure accumulates 1d10 rads per turn; yes rads, not milirads. A ten-minute exposure can easily expose a person to enough radiation to kill them (remember how fast Mr. Spock went down in Star Trek II: Wrath of Khan?). Radiation suits are lined with lead and gold and typically offer SP6 to SP10 against radiation (RSP – radiation stopping power), each RSP blocks 1 rad per turn. I guess Spock should have put one on.

Nuclear Weaponry

Nuclear ordinance is one of the quickest ways to get irradiated to a golden crisp. The basebook covers the immediate effects of a nuke; big explosions and EMP, but the lingering nasty effects of a nuke are covered here.

Initial radiation generated by a nuclear weapon blast is calculated this way:
*Up to x2.0 of the Blast rating generates Kills x100 rads
*Up to x4.0 of the Blast rating generates Kills x50 rads

So a 20K Blast 10 nuclear missile will generate 2000 rads out to 20 hexes (1000m) and 1000 rads out to 40 hexes (2000m).

Residual radiation is the lingering radiation in the crater. The crater need not be visually obvious, particularly in the case of air-burst explosives. Residual radiation is calculated this way:
* (A/Y) x5 = RPT (rads per turn); A = months since blast, Y = Kills of initial blast
*The above covers the crater; half of this intensity out to 2x of the crater radius (initial Blast)

Using the same missile as above, having it gone off 7 months ago; the base crater will radiate 1.75 rads per turn out to 500m (Blast 10) and 0.875 rads per turn out to 1000m.

Solar Flare

Solar flares are a pain in the butt, what with a star being a massive nuclear reactor at the center of every star system. Solar flares disrupt communications, interrupt power sources, corrode solar panels and make pretty lights. Oh yeah, they can also give out several lifetimes' worth of radiation in a six-hour period. During a solar flare you want to be on an ozone-shielded planet, behind a colony wall with sufficient shielding, or deep underground. Fortunately solar flares are not terribly common and most colony or ship sensors will usually give at least 2-3 hours warning to get to shelter. This is why almost all smaller ships will have a small heavily shielded "storm shelter" for 20-30 people (sufficient supplies for a couple weeks).

To determine if there is a solar flare, roll 2d10 each month and subtract 1 for every month since the last flare. If the total is 2 or less, there is a solar flare that month. A solar flare lasts for 1d10 days (roll 1d10 to determine the hours on the last day of the flare). A solar flare has a Strength rating which determines the number of d10 rads of radiation absorbed per hour (yes again rads, not milirads). Thus a strength 4 solar flare will generate 4d10 rads per hour.

d100	Strength
01-23	1
24-42	2
43-59	3
60-72	4
73-83	5
84-90	6
91-95	7
96-98	8
99	9
100	10

On the plus side, when traveling near a planet in the Van Ellen belts, the damage of a solar flare is reduced by the average strength of the radiation belts (count the strongest one twice). The downside of this is that the ship is likely moving quickly and won't be in the radiation belts long, and there is a chance of getting more radiation from the radiation belt than the solar flare itself.

Realistic Radiation Effects

Any temporary decreases in stats without a duration will return proportionately over the same duration as they were lost. All radiation absorbed over the last week is added to the immediate dose. A person is more sensitive to radiation the more he has absorbed, and adds half of his lifetime total radiation to the immediate dose.

Example: A 25 year old person on Earth has absorbed 6,250 milirads of radiation from cosmic sources (250 per year). He then gets exposed to 300 milirads of radiation from a close source. When determining his immediate dose effects, he is treated as having exposed to 300 milirads. Three days later he is exposed to another 150 milirads

and is treated as being exposed to 450 milirads. His lifetime total is now 6,700 milirads (the 250 per year is over a long period and not included in the immediate dose formula).

All stat losses below except for temporary BOD loss are cumulative. For death chances, reroll at the new % when the immediate dose reaches the next threshold.

Immediate Dose (milirads)	% Stat Reduce	% Temp BOD	% Perm BOD	DEX REF	ATTR *	INT	COOL	Suscept. Disease	Damage (lethal)	Chance Death
<50	--	--	--	--	--	--	--	--	--	--
50-100	5%	-1 for 2d10+ 4 hours	--	--	--	--	--	--	--	--
101-200	40%	-1 for 2d10+ 4 hours	--	-1	--	--	--	+10%	--	2%+BTM 2 months
201-300	70%	-2 for 2d10+ 4 hours	--	-1	--	--	--	+30%	--	7%+BTM 2 months
301-400	90%	-2 for 1d3 days	-1	-1	-2 patch y hair loss	--	--	+60%	1d4	30%+BTM 1d6-1 weeks
401-500	100%	-1 for 1d6+1 days	-1	--	-1 total hair loss	--	--	+100%	1d6	50%+BTM 3d10 days
501-750	100%	-1 for 1d10 days	-1	-1	--	--	--	+100%	1d8	75%+BTM 3d6+2 days
751-1000	100%	-1 for 2d10+ 1 days	-1	-1	--	--	--	+100%	1d10	90% 1d10+4 days
1001-5000	100%	-2 for 3d10 days	-1	-1	-1	-2	-2	+100%	2d6	95% 1d6+1 days
>5000 (5 rads)	100%	-1 per 8 hours	-1	-2	-1	-3	-3	+100%	2d10	100% 5d10 hours

* This also decreases the Beautiful Perk if the individual has it.

Heroic Radiation Effects

When exposed to large doses of radiation, in rads, the victim must make a Body Type (BOD) check (1d10 and roll under BOD stat with modifiers below) for each one of these three effects, starting from right column to left. Progression will start with slight illness to serious illness to death. Rolling a 1 will always succeed regardless of modifiers. Characters must make this roll every time more rads are accumulated. When making a check, round down to the nearest 100 rads they have received.

Rads	**Death**	**Serious**	**Slight**
50	N/A	N/A	N/A
100	N/A	N/A	N/A
200	N/A	N/A	N/A
300	N/A	N/A	BT

400	N/A	BT	BT-1
500	BT	BT-1	BT-3
600	BT-1	BT-3	BT-6
700	BT-3	BT-6	BT-9
800	BT-6	BT-9	Auto
900	BT-9	Auto	Auto
100	Auto	Auto	Auto

Slight

Symptoms: nausea, vomiting, headache
Effect: halve BOD, REF and DEX
Onset: 1d6 hours after exposure
Duration: 1d6 days

Serious

Symptoms: incapacitation, severe bloody vomiting, bloody diarrhea, spotting of the skin from internal lesions, bleeding gums, hair loss
Effects: incapacitated
Onset: immediately after "slight" duration ends
Duration: 2d6 days

Death

Symptoms: heart stops beating, lungs stop moving air, brain activity drops to zero, soul vacates the body
Effects: player needs to roll up a new character
Onset: immediately after "serious" duration ends
Duration: in most cases this is permanent, although cloning could be an option

Long-Term Radiation Effects

This table assumes a full body dose. If only a portion of the body is exposed, the GM should adjust the effects accordingly.

Total Dose	Physical Effects	Game Effects
<50	None	None; sure *someone* will get cancer, but this is sci-fi, not a medical journal
100	Mutation	See below
200	Minor cancers	See below
300	Cataracts	Individual will eventually be rendered blind
	Stillbirths	Females becoming pregnant will be increasingly more likely to have stillbirths
400	Leukemia	1 in 300 chance of getting leukemia in 1d4+3 years; % doubles per additional 50 rads
	Moderate cancers	See below
500	Sterility	10% chance; increases to 25% at 500 rads, 50% at 550 rads, 90% at 600 rads, 99% at 650 rads, 100% at 750 or more rads
600	Severe cancers	See below
>700	Fatal cancers	See below; death in 2d10+4 months

Offspring Mutation

Roll 1d10 for each child: 1 – favorable, 2-3 – weird but harmless (extra finger, etc), 4-7 – deformed (-1d6 from 1d3 stats of GM choice), 8-10 – stillbirth.

Cancer

Rules for cancer are very vague because if a person takes such large doses of radiation, they usually don't live to worry about the long-term effects. The GM should feel free to impose any penalties to a character with cancer as they see fit. Of course, medical technology has advanced to almost magical levels by 2050. Considering that by the 2020's they can clone entire people, treating cancer should be fairly simple if its caught in time. Furthermore, if a character gets cancer, roll a d10; on a 1 the cancer goes into remission.

Cybernetics

Just because cybernetics aren't meat doesn't make them immune to radiation. However, they are much more resilient. Roll on the following chart for every 100 rads the cybernetics are exposed to. If results 1, 3 or 4 are rolled more than three times, the effects are permanent. The character's lifetime dose does not apply to cybernetics, only the immediate dose. Radiation shielding on cybernetics effectively reduces the immediate dose by 500 milirads for determining when to roll on this chart.

d6	
1	Cyberoptics cut out for 1d6 turns.
2	Neural pulse. AGIL reduced by 1d3 until the implants are repaired.
3	Cyberaudio cuts out for 1d6 turns.
4	Random cyberlimb cuts out for 1d10 turns. Reroll this if the character has no cyberlimbs.
5	Total neural breakdown. The character is reduced to a twitching epileptic fit for 1d3 rounds.
6	Lucky, no effects.

Radiation Damage

This is the actual damage from radiation, on both people and on electronics. Damage is reduced by tempest hardening, armor and structure to a minimum of 0.1 rad (100 milirads). For computers, partitions count as 0.1 armor and bulkheads count as 3 armor. For every 10 full points of armor, the effects are reduced by one rank.

Roll d8	People Effect	Computer Effect
0	0.1 x1d10 rads	Down for 1 turn on a 6 (d6)
1	1d3 rads	Down for 1d3 turns; Easy Jury Rig or Electronics to fix
2	1d10/2 rads	Down for 1d6 turns; Easy Jury Rig or Electronics to fix
3	1d6+2 rads	Down for 2d6 turns, sensors blind for 1d3 turns; Average Jury Rig or Electronics to fix
4	1d10+2 rads	Down for 2d6 turns, sensors blind for 1d6 turns; Difficult Jury Rig or Electronics to fix
5	3d6 rads	Down indefinitely, sensors blind for 2d6 turns then -10 for 5d10 turns, 3d10% memory erased; Very Difficult Jury Rig or two consecutive Difficult Electronics to fix
6	3d10+5 rads	Down indefinitely, sensors blind 3d10 turns then -20 for 20d10 turns, 4d10+20% memory erased; Nearly Impossible Jury Rig or two consecutive Very Difficult Electronics to fix
7	5d10 rads	Down indefinitely, sensors blind 4d10 turns then -40 permanently, all memory erased; Nearly Impossible Jury rig *and* two consecutive Nearly Impossible Electronics to fix
8	8d10 rads	Computer fried, all memory erased, sensors destroyed.

Being Spaced

While the above covers the specifics of various space hazards, being spaced is a particularly nasty way to die, as it combines multiple nasty ways to die. In short a person who gets spaced will suffer:
1) Explosive decompression. His lungs burst from the uneven pressure (2d4 damage) unless he is smart enough to exhale before hitting vacuum (1d4 damage instead), and the nitrogen "boils" out of his blood, rupturing blood vessels, causing 1d3 damage per turn. Luckily he will be dead long before brain damage occurs, although if he survives he will still lose his eyes and most likely his eardrums.
2) Radiation. Being within a stellar system unshielded can yield 50 to 500 rads per turn depending on the star type and distance away the victim is.
3) Extreme Heat. The side facing the parent star will be bathed in infrared and other "heat" radiation, inflicting 2d6 burning damage per turn to that side.
4) Extreme Cold. The side facing away from the parent star will be subjected to the balmy outer space temperature 3° warmer than absolute zero.
5) Micrometeorites. If the GM is feeling particularly nasty, each turn there is a 1 on a d10 chance the poor victim gets tagged by micrometeorites and takes additional damage (roll the chart below under micrometeorites).

All damage is lethal. The average human won't last more than 30 seconds (3 turns) in space.

Getting spaced is pretty much a death sentence. However, on fleets where cybernetics are standard (such as Macross Galaxy), the brain can be transferred into a cybernetic body.

Van Ellen Belts

Planets with active cores generate a radiation field around themselves. Rocky planets like the Earth will usually have 2-3 belts, gas/ice giants like Neptune will usually have 3-6 belts, and large gas giants such as Jupiter have nearly a dozen. These ratings are largely approximated for game play and may not reflect the actual radiation strength of the belts, particularly for Jupiter.

A number of times per day on the chart below, a roll is needed on the above radiation damage table. Passing through multiple belts requires a roll for each belt passed through. Thus leaving or landing on Earth requires 3 rolls. This only applies to those not sufficiently protected (as outlined above).

Example: A variable fighter pilot spends a day patrolling in orbit around a Neptune-like planet, mostly in the #4 belt. The player will have to roll 4 times on the above radiation damage chart. He could absorb as much as 320 rads! (8d10 max 80 x4 rolls = 320) Furthermore, the player would need to make 4 rolls on the computer effect to determine the effects on his variable fighter's computer system.

Belt	Rad STR	Belt	Rad STR
Jupiter 1	5	Earth Inner	2
Jupiter 2	10*	Earth Outer	1
Jupiter 3	9	Saturn/Neptune/Uranus 1	4
Jupiter 4	7	Saturn/Neptune/Uranus 2	4
Jupiter 5	5	Saturn/Neptune/Uranus 3	4
Jupiter 6	4	Saturn/Neptune/Uranus 4	3
Jupiter 7	4	Saturn/Neptune/Uranus 5	1
Jupiter 8	3		
Jupiter 9	2		

Jupiter 10	1		

* This rating should actually be 22, but is reduced for game play value. The GM is free to use the more realistic rating if they wish.

Fold Faults

Fold faults are "ripples" in space that prevent superdimensional folding, which blocks space fold travel and communications. A ship traveling in superdimensional space that crosses a fold fault is violently thrown back into realspace and suffers an automatic engine hit and the space fold engine is damaged.

Micrometeorites

Space isn't as clean and empty as everyone thinks. Space is full of debris; parts from mecha and ships from old battles, small chunks of rock and ice, and all kinds of junk. Impacts with paint flecks and other particles happen many times a day and do little more than scratch your paintjob. Collisions with sand grain-sized junk can happen, at a cumulative 0.1% per day (cumulative 0.3% per day in the main asteroid belt). If a collision occurs, roll on the following chart. Micrometeorites travel so fast that all armor is halved. Luckily the hyper carbon alloy used on the hulls of ships and stations will shrug off anything that doesn't inflict Kills of damage.

d100	Damage
01-50	1 hit
51-75	1d3 hits
76-90	1d6 hits
91-95	1d10 hits
96-98	2d10 hits
99	3d10 hits
100	5d10 hits and roll again

Asteroids & Meteors

Anything the size of a small car or bigger. Most autopilots have navigation programs to avoid asteroids as they are big enough to pick up on even the lowest rating sensors, and they are luckily quite rare outside of asteroid belts. If a mecha, ship or installation is hit by an asteroid, there is little point in worrying anymore. If the GM really wants to figure damage, treat asteroids as nuclear warheads (minus the radiation) that inflict 25K per ton.

Planetary Rings & Comets

Passing through rings of ice, dust and rock can be hazardous. So can passing through the tail of a comet. Rings and comets have a hazard rating which indicates the number of d6 to roll each hour. Some rings have less than 1 for HR; in these instances you roll each interval where the HR reaches 1 and resets to 0. These hazard ratings are approximations for game play and may not reflect the true dangers of the rings. Some example rings and hazards:

Ring	Hazard Rating
Saturn Ring A	5
Saturn Ring B	0
Saturn Ring C	2
Saturn Ring D	2
Saturn Ring E	0

Saturn Ring F	0
Saturn Ring G	0
Uranus Rings	0.1

When passing through the rings of Uranus, the hazard rating reaches 1 every ten hours.

What this hazard rating means is the GM rolls that many d6 in damage. Thus, passing through Saturn ring A is 5d6 damage per hour.

Planetary Environments

Not all planets are nice like Earth or Eden. Some are downright inhospitable.

No Atmosphere

Should your mecha or suit be breached, you suffer decompression, radiation and space exposure. See "getting spaced" above for all the gory details.

High Gravity & Pressure

As shown in the basebook, humans can only take just so much gravity before becoming crushed. A person's weight is increased based on the gravity of the planet. A human who weighs 90kg (200lb) on Earth would weigh twice that much on a planet with 2G, and triple that on a planet with 3G. Such weight makes it difficult or impossible to move, as their muscles and bones aren't strong enough to withstand the increase in weight, the lungs strain to draw breath, and the heart overworks trying to move blood through the body. Likewise, a planet with a heavy atmosphere such as Venus causes similar problems.

Temperature Extremes

Some planets are extremely hot while others are extremely cold. Mecha require the desert or arctic environmental package to function on such planets. Depending on the temperature, characters could take anywhere from 1 hit up to 1K per turn. Some planets are so hot that even mecha cannot survive for more than a few minutes, or so cold that even hyper carbon alloy becomes too brittle and shatters under its own weight.

Some Examples: (material examples assume 1 earth atmosphere standard)

Absolute Heat Limit	2.538×10^{32}°F
	[253,800,000,000,000,000,000,000,000,000,000°F]
Sol core	156,999,726.5°C (282,599,540.33°F)
Blue Supergiant surface	39,726.85°C (71,540.33°F) -average
Jupiter near core	35,726.85°C (58,940.33°F)
Jupiter interior	9,726.82°C (17,540.28°F)
-City 7 thermal limit*	6,000°C (10,832°F)
Sol surface	5,504.85°C (9,940.73°F)
Red Supergiant surface	3,726.85°C (6,740.33°F) -average
-tungsten melts	3,400°C (6,150°F)
-lead boils	1,749°C (3,180.2°F)
-titanium melts	1,670°C (3,040°F)
Reentry to Earth atmosphere	1,650°C (3,000°F)
-iron melts	1,510°C (2,750°F)
-steel melts	1,370°C (2,500°F)

-aluminum melts	660°C (1,220°F)
Venus surface	460°C (860°F)
Nuclear reactor critical point	374°C (705.2°F)
-lead melts	327.5°C (621°F)
-gasoline ignites	280°C (536°F)
Mercury surface	66.85°C (152.33°F)
-water boils	100°C (212°F)
Earth heat record (Libya)	57.8°C (136°F)
-water freezes	0°C (32°F)
Earth cold record (Vostok)	-89.2°C (-128.6°F)
Jupiter surface	-108.15°C (-162.67°F)
Europa surface	-171.15°C (-276.07°F)
-liquid nitrogen	-210°C (-346°F)
-liquid oxygen (LOX)	-222.65°C (-368.77°F)
Pluto surface	-229.15°C (-375.14°F)
-liquid hydrogen	-252.87°C (-423.17°F)
Outer space (average)	-270°C (-454°F)
Absolute Zero	-273.15°C (-459.67°F)

There are no hard and easy rules for how much damage at what temperature range, so the GM should assign a damage per time period based on how extreme the temperature is and what kind of protection is being used.

* The New Macross Class armor can withstand up to 6,000°C maximum, but it showed signs of damage at 5,000°C.

Absolute zero means that the temperature is so cold that even subatomic particles (neutrons, electrons, etc) stop moving. The absolute heat limit is the temperature at which all currently understood laws of physics simply no longer apply and the effects cannot be calculated. Such staggering temperature only existed (theoretically) shortly after the Big Bang.

Heat

A human will take heat damage if his body temperature is increased above normal (37ºC). At 39ºC a human will become feverish and dizzy (-1 to all skills, 1D6 STUN damage per minute). For every 2 degrees above this, there is an additional -1 to all skills, and the target takes +1D6 STUN damage per minute (that is, at 43ºC, he will be taking 4D6 STUN per minute!) .

At 43ºC, the subject will also take 1D6 killing damage, lose 1 one point in INT (unrecoverable brain damage). At 44ºC he will take another 1D6 killing damage, and lose 1 one more point in INT, and so on, for every 1 degree thereafter. Usually, the subject will die from brain damage when his INT reaches 0.

This is assuming a gradual increase. If the subject's temperature is instantly raised to 52ºC instantly, he will take 13D6 STUN hits, 9D6 killing damage (and thus 9D6 more STUN), and lost 9 INT, at that instant. This is usually fatal. Remember, however, most adult males mass 70 - 80 kg.

Cold

A human will take chill damage if his body temperature is taken below normal (37ºC). For every degree below 36ºC, the will be at -1 to all skills and take 1D6 STUN damage per minute. At 32ºC he is in hypothermia, and takes 1D6 killing damage every minute, and should be severely incapacitated with shivering. Thus at 30ºC he is taking both STUN and killing damage simultaneously.

It is also possible to damage or weaken objects by cooling them to a brittle point. Chilling most metals down to -30ºC will lower its SP and SDP by half (it will return to normal when it's temperature returns to normal). Halve the SP and SDP again for every -30ºC thereafter, down to Absolute Zero. Assume all mecha, vehicles and ships have sufficient internal heating to keep them from Absolute Zero naturally.

Corrosive Atmosphere

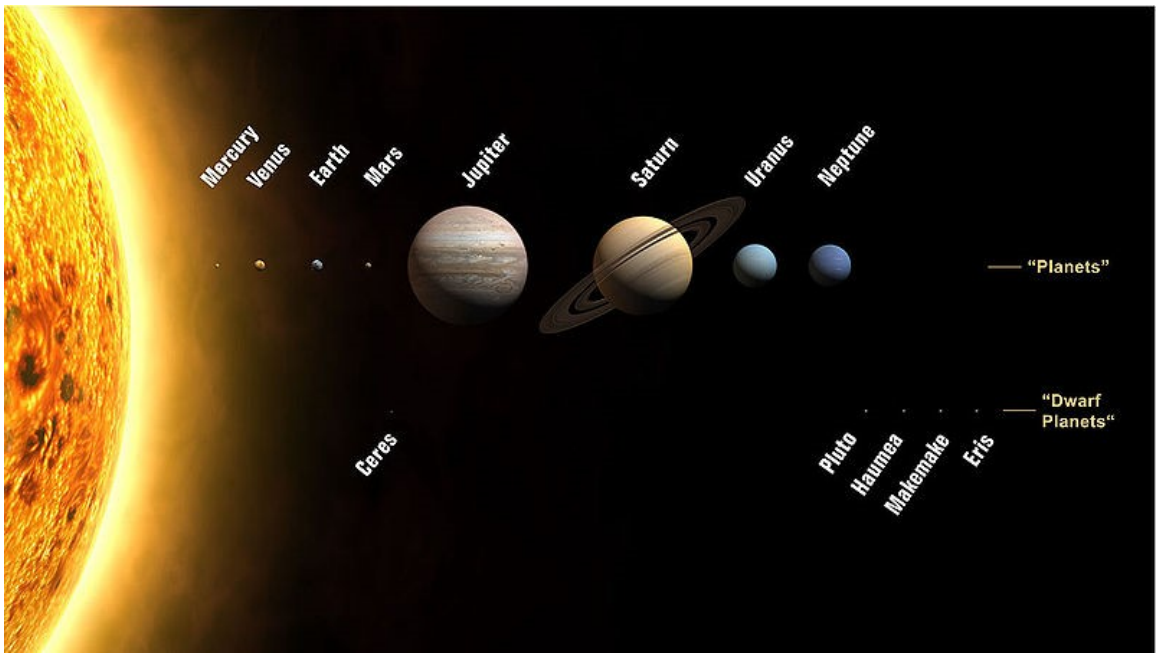
Planets such as Venus have acidic atmospheres. They rain various types of acid, and the clouds are composed of corrosive droplets. Most mecha and capital ships can withstand passing through these clouds to land or take off, but will suffer damage from prolonged exposure.

Depending on the concentration of the corrosive elements, mecha and capital ships are unharmed for a number of intervals equal to their armor DC. After this, they will suffer 1K (at mekton scale, scale up/down as needed) to all exposed locations per interval. Once half of their armor SP is gone, they begin taking equal damage to the servo underneath at the same interval, and possibly risking critical hit location rolls.

For example, a VF-1 on a strongly corrosive planet can go for one hour safely. After that, it loses 1K to all armor locations per hour. Once the armor SP is reduced to half, it takes 1K to all armor and servo locations per hour; at this point the internal systems can be damaged.

Chapter 12 – The Sol System

This chapter includes a combination of real-world stellar information combined with information particular to the Macross Saga. This serves as a guide to our home system as well as an example of a star system fit for human colonization. This section is liable to become outdated as more discoveries are made.



Sol

Our sun is classified as a G2V star; the G2 signifying an average surface temperature of 5,500 degrees Kelvin, and the V indicating a main sequence star (nuclear fusion of hydrogen into helium, and the star is not changing size). The sun has a white color, but due to atmospheric scattering it appears yellow on earth. It accounts for more than 99% of the star system's mass. The sun is also sometimes called Helios.

- Diameter: 1.392×10^{6} km
- Circumference: 4.373×10^{6} km
- Surface Area: 6.09×10^{18} m² (11,900 Earths)
- Volume: 1.41×10^{27} m³ (1,300,000 Earths)
- Mass: 1.988 435×10^{30} kg (332,946 Earths)

Vulcanoid Asteroids

- between 0.08 and 0.21 AU from Sol

Mercury

Mercury has no atmosphere to speak of, and if it had one, it was blown away by the strong solar wind long ago. Some current theories now say that current day Mercury is nothing more than the core of the planet after the sun evaporated the rocky surface and blew it into space.

- 0.39 AU from Sol.
- Equatorial diameter: 4,879.4 km
- Orbit time: 88 terran days
- Surface temperature: 700 degrees Kelvin in the sun to 90 degrees Kelvin in the shadow (430 to -180 Celsius)
- No confirmed natural satellites

Mercury-Crosser Asteroids

- 2101 Adonis - 0.5—1.2 km; 0.441 AU to 3.307 AU

Venus

Venus has no magnetic field and thus gets baked by solar radiation. The atmosphere is 95% carbon dioxide with traces of nitrogen, and the surface pressure is 75 to 100 atmospheres. Surface temperature ranges from 855 to 885 degrees F (455 to 475 C). The clouds form a layer, ending 22 miles above the surface. This cloud layer is actually three distinct layers. The two upper layers are primarily sulfuric acid and chlorine droplets, while the lowest layer is phosphoric acid (H_3PO_4) solution. There is strong lightning activity as well, although no high-frequency (0.125 to 16 MHz) radio waves were detected; this is common to lightning. The surface has some unusually huge shield volcanoes and arachnoids, and seismic activity has been detected in the crust. A huge double atmospheric vortex exists at the south pole.

At 50km above the surface the atmospheric pressure is 1 Bar (equal to earth), 0.9 G and temperatures of 0 to 50 degrees C. It is argued the resources for life are abundant at this height and suitable for colonization.

- 0.72 AU from Sol
- Equatorial diameter: 12,103.7 km
- No confirmed natural satellites

2002 VE68 - quasi-satellite, this asteroid is also a Mercury- and Earth-crosser. See Venus-crosser Asteroids for more information

Venus-Crosser Asteroids

- 4183 Cuno - 4-9 km in diameter

Earth

- 1 AU from Sol
- Diameter: Equatorial 12,756.270 km, Polar 12,713.500 km, Mean 12,745.591 km
- 1 confirmed natural satellite
    - **Africa**
        - Grand Cannon III (Victoria Autonomous Region) - construction began in 2004, October. Construction was incomplete.
    - **Eurasia**
        - Central Russia Administrative Region
            - St. Petersburg [Leningrad] - the Anti-UN Army uses strategic [tactical] thermonuclear reaction weaponry and destroys the city in 2006, October as a demonstration of their capability and willingness to use such weapons against the UN.
        - Kazakh Autonomous Region - location of rioting in 2005, January.
        - Kirghiz Autonomous Regions - location of rioting in 2005, January.
        - Garalia
        - [Great Britain] - Liverpool
        - Bjorn City (Located in the Danube Area)
    - **Japan**
        - UN Far East Command Headquarters
        - Yokohama
    - **North America**
        - Alaska
            - (Earth) UN Military Headquarters (for anti-stellar-warfare) - Construction began in 2002, May.
            - Grand Cannon I (Same site as UN Military Headquarters) - Construction began in 2002, May with completion on 2010, January 10. Intact but nonfunctional ruins.
            - Macross City - reconstruction begins and is completed in 2010, May. Located near the Grand Cannon I site. By far the largest and best city in the UN. Macross city is home to the Macross, U.N. Government and Military HQ.
            - Macross Lake
            - SDF-1 Macross
        - California (Los Cupid, Mojave Desert)
        - Gante City

        - Highlander City - Located a few hours from Macross City (by air). This city was a thriving pretty good just after the SW1 and attracted a lot of show business types.
        - Lonesco City - A city best known for being the city that Kamjin took Minmei hostage.
        - Onogi City - A major industrial city (Reaction Engines) located not far from Macross City. Onogi is on a coast and is possibly located east of Macross City.
        - Ontario
        - South Coast City - City most likely located on a southern coast line. In 2012 the City had become self-sufficient enough to leave direct U.N. control and be self-govern.
        - Trad City - Trad City is located in old America and has high Zentraedi presence (50% population is Zentraedi.)
    - **Oceania**
        - Grand Cannon II (Australian Autonomous Region) - construction began in 2004, March. The under-construction Cannon is destroyed in 2005, November during an Anti-UN Army retaliatory attack on UN Forces
        - Mayan Island (South Pacific Ocean) - site of Protoculture phenomenon and a dispute over the discovery of it, which resulted in the secret deployment of the VF-0 and SV-51 by the UN Government and Anti-UN forces in 2008, September. (The events are kept secret for at least five decades.)
        - South Ataria Island
        - New Anderson Base - Guam. First mentioned: 2044 (VFF stationed at the base - though could be on another planet, a la New Edwards of Eden.)
    - **South America**
        - Grand Cannon V (Brazilian Autonomous Region) - construction began in 2007, May. Construction incomplete.
    - **Location - unknown**
        - Eagle Nest Aerial Tactics Centre - in 2029 Captain Milia Jenius is appointed as an instructor at the centre.
        - New Mirimar Base

Earth Orbit

- Van Allen Radiation Belts
- Factory Satellite - in Earth orbit at L5 point from 2011, November.
- Earth Defense Force (On 2037, January 23rd, Isamu Alva Dyson is assigned to it.)
- Space Colony Clusters [Bunches] - survived SWI unscathed. Location unknown

Earth-Sun Lagrange Points

- L4
    - Earth's Lagrange 4 space unit: Suzie Newtlet ends her test pilot assignment and relocates to the unit in 2049

Moon

- Equatorial diameter: 3,476.2 km
- Apollo Lunar Base Colony (In the Sea of Tranquility on the Lunar surface) - In a factory beneath the Base, using feedback from restoration work on the ASS-1, construction begins on SDF-2, a stellar space warship entirely of Earth origin in 2003, November. Construction of the large-scale permanent base began in 2000, October. Patrols of the Solar System begin in 2010, June, using Super Valkyries based at Apollo Base
- Moon Riverside City (Lunar surface's civilian sector, Earth's Moon)
- Grand Cannon IV (North Polar Region) - construction began in 2006, March. Construction incomplete.
- Test site of the first thermonuclear reaction bomb (Lunar Surface) - detonation occurred in 2004, February

Moon-Earth Lagrange Points

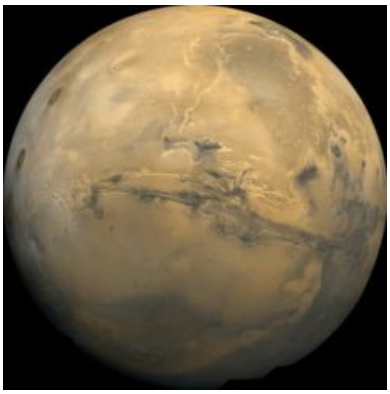
- L4
    - Kordylewski cloud - at L4 and L5; they could be at least 14,000 km across, about the size of the Earth
- L5
    - Manufacturing Station (in Lunar orbit) - Large-scale station and construction site of ARMD Carriers and Oberth Destroyers from 2003, April. Station presumably damaged during SWI. Construction of the station began in 2001, May
    - New Frontier (Ship Yards and Space Colony) This could be the manufacturing station post SWI

Earth-Near Asteroids

- Earth-Crosser Asteroids
    - 3753 Cruithne - Earth's second Moon! ~5 km; 0.998 AU from Sol
- Arjuna Asteroids
- Amor Asteroids
    - 1221A Amor - 1.5? km; 1.086 AU to 2.754 AU
    - 433 Eros - 13×13×33 km; 1.133 AU to 1.783 AU from Sol
    - 3908 Nix - Diameter: 1 - 2 km
- Apollo Asteroids
    - 1862 Apollo - 1.7 km; 0.647 AU to 2.295 AU
    - 69230 Hermes - radar observations showed it to be a binary asteroid with two equal-sized components almost in contact with one another. Each component is about 300–450 meters in diameter; has passed within 0.005 AU of the Earth (approximately 1.5 the distance of the Moon.)
    - 1566 Icarus - 1.4 km; 0.187 AU to 1.969 AU
    - 25143 Itokawa - 540 x 270 x 210 meters; 0.953 AU to 1.695 AU from Sol
- Aten Asteroids
    - 2062 Aten - 0.9 km; 0.790 AU to 1.143 AU

Mars

Mars is an arid desert-like planet. Massive sandstorms are frequent. There are gullies and channels in the terrain, suggesting the existence of water at some point; and the Ares Vallis is believed to be an ancient flood plain. It is further believed that at one point Mars was much warmer and wetter, with a thicker atmosphere. The Meridiani Planum has large deposits of hematite, further indicating the presence of water at some point. Research conducted in 2008-2009 have indicated large quantities of water ice buried under the surface.



- 1.5 AU from Sol
- Equatorial diameter: 6,804.9 km
- H.G. Wells City (First mentioned as birthplace of Gamlin Kizaki in 2026, January
- SALLA Base - permanent base. Construction began in 2001, July. Manned by UN Spacy personnel from 2003, November until 2005, August, with withdrawal from Mars Base led by Harry Miler. The return fleet from Mars is destroyed at 18:00 on September 8 by the Anti-UN hijacked Oberth class space destroyer Tsiolkovsky with a loss of 3,055 UN Forces personnel. Base is destroyed in 2009 when the Macross escapes from a Zentraedi trap.
- 2 confirmed natural satellites; both in degrading orbits

Phobos

- 26.8 × 21 × 18.4 Km
- Orbit: 9,235.6 to 9,518.8 km from Mars
- Its low orbit means that Phobos will eventually be destroyed: tidal forces are lowering its orbit, currently at the rate of about 1.8 meters per century, and in about 50 million years it will either impact the surface of Mars or (more likely) break up into a planetary ring. Because of its ellipsoidal shape alone, the gravity on Phobos' surface varies by about 210%; the tidal forces raised by Mars more than double this variation (to about 450%) because they compensate for a little more than half of Phobos' gravity at its sub- and anti-Mars poles. As seen from Phobos, Mars would be 6400 times larger and 2500 times brighter than the full Moon as seen from Earth, taking up a full 1/4 of the width of a celestial hemisphere

Deimos

- 15.0 × 12 × 10.4 Km

- Mean orbital radius: 23,460 km
- As seen from Deimos, Mars would be 1000 times larger and 400 times brighter than the full Moon as seen from Earth, taking up a full 1/11 of the width of a celestial hemisphere. Deimos moves away from Mars at a rate of 3 inches per year, and will eventually be thrown out of orbit and into space.

Mars Trojans

- L4
    - 5261 Eureka - 2-4 km
        - It trails Mars at a distance varying by only 0.3 AU during each revolution. It's minimum distances from the Earth, Venus and Jupiter are 0.5, 0.8 and 3.5 AU, respectively
    - 1999 UJ_7
- L5
    - 1998 VF_{31}, 2001 DH_{47}, 2001 FG_{24}, & 2001 FR_{127}

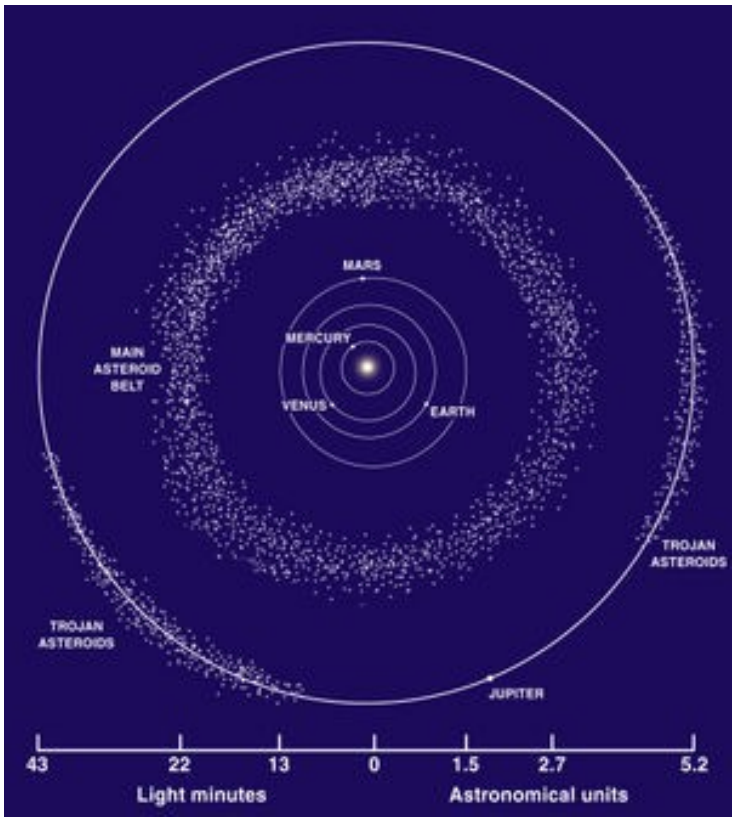
Mars Co-Orbitals

- These are not destined to remain as Trojans as they'll be perturbed away by Mars within the next 500,000 years or so.
    - 1998 QH_{56} & 1998 SD_4

Mars-Crosser Asteroids

Asteroid Belt

Despite popular imagery, the asteroid belt is mostly empty. The asteroids are spread over such a large volume that it would be highly improbable to reach an asteroid without aiming carefully. Nonetheless, tens of thousands of asteroids are currently known, and estimates of the total number range in the millions. About 220 of them are larger than 100 km. The total mass of the Asteroid belt is estimated to be $2.3 \times 1{,}021$ kilograms, which is 1/35th that of the Earth's Moon. And of that total mass, one-third is accounted for by Ceres alone.



- Ceres Family
    - A group of asteroids with a semi-major axis of about 2.74-2.80 AU and an orbital eccentricity of approximately 0.08-0.17
    - There are some indications that the Cererian surface is relatively warm and that it may have a tenuous atmosphere and frost. The maximum temperature, when the Sun is overhead, has been estimated to be 235 K (about -38° C). A more recent study suggests the presence of a rocky core overlain with an icy mantle. This mantle of thickness from 120 to 60 km could contain 200 million cubic kilometers of water, which is more than the amount of fresh water on the Earth
        - 1 Ceres - 975×909 km; 2.546 AU to 2.988 AU
            - Ceres is under much debate to its status whether it is a planet, dwarf planet or asteroid. It is spherical, unlike the asteroids of similar or lesser gravity. As of 2009 it is classified as a dwarf planet.
- 255 Oppavia - 57.0 km; 2.523 AU to 2.966 AU
- 374 Burgundia - 45.0 km; 2.56 AU to 3.002 AU
- Eros Family
    - This is a prominent family of asteroids that are believed to have formed as a result from an ancient catastrophic collision between asteroids. Members of the family share similar orbits between 2.99 and 3.03 AU. Currently there are about 480 members known.
        - 221 Eros - 104.0 km; 2.701 AU 3.322 AU from Sol
- Juno Clump

    - 3 Juno - 290×240 km; 1.978 AU to 3.357 AU from Sol
        - The maximum temperature on the surface, when the sun is overhead, has been estimated to be about 293 K, or about +20°C. Infrared images reveal that it possesses an approximately 100 km wide crater or ejecta feature, the result of a geologically young impact.
- Hirayama Families
- 526 Jena - ?? Km; 2.682 AU to 3.551 AU from Sol
- 846 Lipperta - ?? Km; 2.537 AU to 3.705 AU from Sol
- 468 Lina
- Themis Family - mean distance of 3.13 AU from Sol
    - 24 Themis - 228 km; 2.715 AU to 3.545 AU from Sol
    - 62 Erato - 95.4 km; 2.562 AU to 3.681 AU from Sol
    - 90 Antiope - 110±16 km; 2.664 AU to 3.648 AU from Sol
    - 104 Klymene - 123.7 km; 2.686 AU to 3.625 AU from Sol
    - 171 Ophilia - 116.7 km; 2.732 AU to 3.532 AU from Sol
- 2 Pallas - 570×525×500 km; 2.135 AU to 3.410 AU from Sol
- Vesta Family - about 235 members are currently known
    - 4 Vesta - 468.3 km; 2.152 AU to 2.571 AU from Sol. In 1996 the Hubble Space Telescope (see image below) detected a huge Vestian crater, 430 kilometers across and perhaps a billion years old. It is thought that this crater may be the source of the small V-type asteroids (or Vestoids) observed today
    - 9969 Braille - Its shape is highly elongated; it measures 2.2 by 0.6 kilometers.
- Cybeles Family
    - 65 Cybele - 237.3 km, 3.077 AU to 3.794 AU from Sol
        - A hint of a possible 11 km wide satellite orbiting Cybele has been detected
- 87 Sylvia - 384 x 264 x 232 km; 3.213 AU to 3.768 AU from Sol
    - Romulus - 18 +/- 4 km; orbits at 1,356 +/- 5 km
    - Remus - 7 +/- 2 km; orbits at 706 +/- 5 km
        - From the surface of Sylvia, Romulus and Remus would appear roughly the same size. From Remus, the inner moon, Sylvia appears huge, roughly 30º x 18º degrees across, while its view of Romulus varies between 1.59º and 0.50º across. From Romulus, Sylvia measures 16º~10º across, while Remus varies between 0.62º and 0.19º

Jupiter

Jupiter is the largest planet in our solar system. The outer layers are composed of 88-92% hydrogen and 8-12% helium, with some other trace elements such as sulfur, methane, carbon, ethane, water vapor, ammonia, neon and phosphine to name a few. This gas layer extends down 1,000km where it has a smooth gradation into liquid metallic hydrogen. This liquid layer is believed to comprise 78% of the diameter of the planet. Liquid metallic hydrogen forms at a temperature of 10,000K and a pressure of 200 GPa.

While currently unconfirmed, it is generally accepted that Jupiter does indeed have a solid rocky core with a core boundary temperature of 36,000K and a pressure of 3,000-4,500 GPa. This makes the interior of Jupiter hotter than the surface of our sun.

- 4.95 AU to 5.46 AU from Sol
- *Equatorial diameter:* 142,984 km, *Polar diameter:* 133,709 km
- Rings of Jupiter - 3: Halo, Main Ring, & Gossamer Ring
- 63 confirmed natural satellites; 47 of these have retrograde orbits; the 4 largest are referred to as Galilean moons, named after Galileo.
    - Io - 3,660.0 × 3,637.4 × 3,630.6 Km
        - Io is a volcanically active body, with over 100 mountains and over 40 active volcanoes. It is believed to be composed of silicate rock with a molten iron or iron sulfide core. It has an extremely thin atmosphere of sulfur dioxide.
    - Europa - 3,121.6 Km
        - Europa is believed to have a 100km deep ocean of water covered in a 100km thick layer of water ice.
        - Europa hosts a number of UN Government mining bases (for water, amongst other minerals).
            - Europa Base 1 through 6
            - Europa Base 7 (first mentioned on February 9, 2038)
    - Ganymede - 5,262.4 Km
        - Ganymede is a composite of smooth terrain mixed with rocky terrain. The moon is composed of silicate rock with a saltwater ocean nearly 200km below the surface. It has a faint atmosphere of O, O_2, O_3 (ozone) and molecular hydrogen.
        - UN Government water and mining colony
    - Callisto - 4,820.6 Km

        - It is believed that there may be an ocean of fresh water at depths of more than 100km. It has an extremely thin atmosphere of carbon dioxide and possibly molecular oxygen.
    - White Flora Satellite City

Jupiter Trojan Asteroids

The Trojan asteroids lie between 5.05 AU and 5.40 AU, and lie in elongated, curved regions around the two Lagrangian points 60° ahead and behind of Jupiter.

- Greek Camp
    - 588 Achilles - 135.5 km
    - 624 Hektor - 370 × 195 km.
- Trojan Camp - orbits the L_5 Lagrangian point of the Sun-Jupiter system.
- 617 Patroclus - 105km

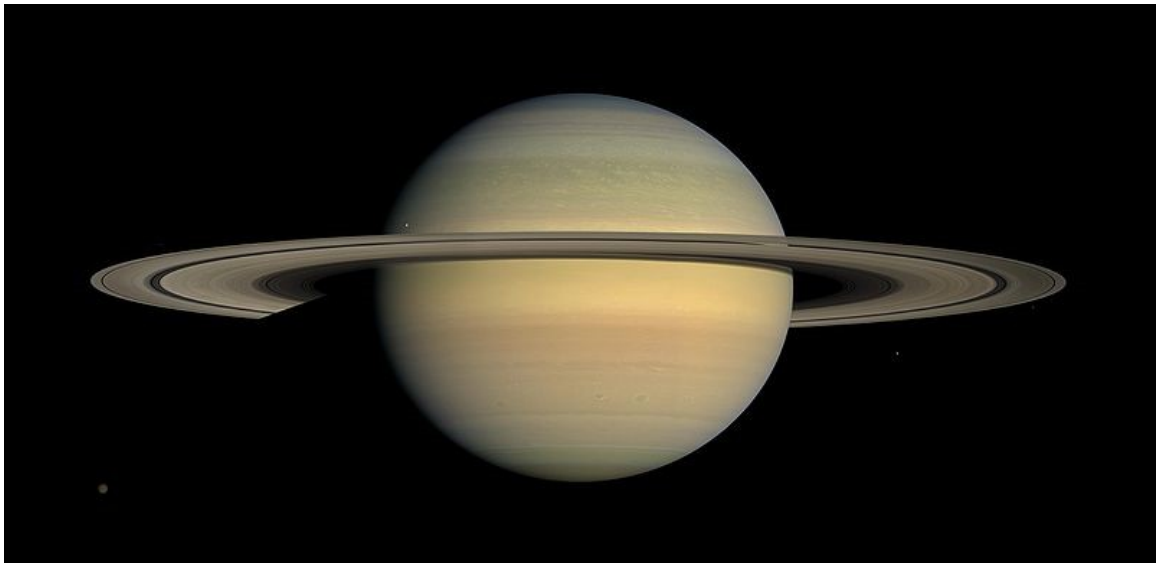
Centaur Planetoids

A class of icy planetoids that orbit Sol between Jupiter and Neptune. Centaurs are not in stable orbits and will eventually be removed by the giant planets. Centaurs are dark in color, because their icy surfaces have darkened after long exposure to solar radiation and the solar wind. However, fresh craters excavate brighter, more reflective ice from below the surface.

- 8405 Asbolus - 66±4 km; ?? AU from Sol
- 2060 Chiron - 132 - 142 km; 8.45 AU to 18.891 AU from Sol.
    - Initially classified as an asteroid, later dispute arose as to whether it was an asteroid or actually a comet.
- 5145 Pholus - 185 ±16 km; 8.729 AU to 32.136 AU from Sol.
    - Found to be the reddest object observed to date in the Solar System, for which it has been occasionally nicknamed "Big Red". The color has been speculated to be due to organic compounds on its surface. Pholus has shown no signs of cometary activity.

Saturn

Due to a combination of its lower density, rapid rotation, and fluid state, Saturn is an oblate spheroid; that is, it is flattened at the poles and bulges at the equator. Its equatorial and polar radii differ by almost 10%—60,268 km versus 54,364 km. The other gas planets are also oblate, but to a lesser extent. Saturn is the only planet of the Solar System that is less dense than water. Although Saturn's core is considerably denser than water, the average specific density of the planet is 0.69 g/cm³ due to the gaseous atmosphere. Saturn is only 95 Earth masses, compared to Jupiter, which is 318 times the mass of the Earth but only about 20% larger than Saturn.



- 9.02 AU to 10.05 AU from Sol.
- Equatorial diameter: 120,536 km, Polar diameter: 108,728 km.
- Rings of Saturn - Saturn has 15 rings.
- 56 confirmed natural satellites; 27 have retrograde orbits
    - Mimas - 418.2 × 392.4 × 382.8 km.
        - Mimas' low density (1.17) indicates that it is composed mostly of water ice with only a small amount of rock. Due to the tidal forces acting on it, the moon is not perfectly spherical; its longest axis is about 10% longer than the shortest. Mimas' most distinctive feature is a colossal impact crater 130 km across, named Herschel. Herschel's diameter is almost a third of the moon's own diameter; its walls are approximately 5 km high, parts of its floor measure 10 km deep, and its central peak rises 6 km above the crater floor.
    - Enceladus - 512 × 494 × 489 km
        - Given its position in Saturn's E ring, the youthful appearance of portions of Enceladus' surface, the recent discovery of a short-lived atmosphere, and a hot spot near the south pole, it is likely that Enceladus is geologically active today
    - Tethys - 1,071.2 × 1,056.4 × 1051.6 km
        - It is composed almost entirely of water-ice.
          The western hemisphere of Tethys is dominated by a huge impact crater called Odysseus, whose 400 km diameter is nearly 2/5 of that of Tethys itself. The crater is now quite flat (or more precisely, it conforms to Tethys' spherical shape), like the craters on Callisto, without the high ring mountains and central peaks commonly seen on the Moon and Mercury. This is most likely due to the slumping of the weak Tethyan icy crust over geologic time
        - The second major feature seen on Tethys is a huge valley called Ithaca Chasma, 100 km wide and 3 to 5 km deep. It runs 2,000 km long, approximately 3/4 of the way around Tethys' circumference. The Tethyan surface temperature is -187°C

- *Saturn-Tethys Lagrangian Points*
  - Telesto - either 30 x 16 x 16 or 34 x 22 x 22 km
  - Calypso - either 30 x 16 x 16 or 34 x 22 x 22 km
- Dione - 1,118 km
  - Dione is composed completely of water ice.
- *Saturn-Dione Lagrangian Points*
  - Helene - 36 x 32 x 30 km
  - Polydeuces - 13 kmq
- Rhea - 1,528 km
  - Rhea is an icy body with a density of about 1,240 kg/m3. This low density indicates that it has a rocky core taking up less than one-third of the moon's mass with the rest composed of water-ice
- Titan - 5,150 km
  - Titan is the only moon in our solar system to have a dense atmosphere. Titanian volcanism is now believed to be a significant source of the methane in the atmosphere.
  - Titan is about half water ice and half rocky material. It is probably differentiated into several layers with a 3400 km rocky center surrounded by several layers composed of different crystal forms of ice. Its interior may still be hot. Though similar in composition to Rhea and the rest of Saturn's moons, it is denser due to gravitational compression
- Hyperion - 360 x 280 x 225 km
  - Hyperion is composed largely of water ice with only a small amount of rock. It is thought that Hyperion may be similar to a loosely accreted pile of rubble in its physical composition. However, unlike most of Saturn's moons, Hyperion has a low albedo (0.2?0.3), indicating that it is covered by at least a thin layer of dark material. This may be material from Phoebe (which is much darker) that got past Iapetus. Hyperion is redder than Phoebe and closely matches the color of the dark material on Iapetus.
- Iaptus - 1,436 km
  - The low density of Iapetus indicates that it is primarily composed of ice, with only a small amount of rocky materials.
    The overall shape of Iapetus is neither spherical nor ellipsoid — unusual for a large moon; parts of its globe appear to be squashed flat, and its unique equatorial ridge is so high that it visibly distorts the moon's shape even when viewed from a distance.

Uranus

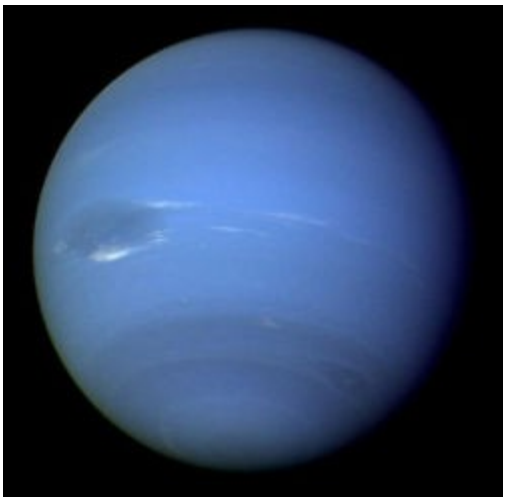
Uranus is similar in composition to Neptune, and both have different compositions from those of the larger gas giants Jupiter and Saturn. As such, astronomers sometimes place them in a separate category, the "ice giants". Uranus's atmosphere, while similar to Jupiter and Saturn's in its primary composition of hydrogen and helium, contains more "ices" such as water, ammonia and methane, along with traces of hydrocarbons. It is the coldest planetary atmosphere in the Solar System, with a

minimum temperature of 49 K (–224 °C). It has a complex, layered cloud structure, with water thought to make up the lowest clouds, and methane thought to make up the uppermost layer of clouds. In contrast the interior of Uranus is mainly composed of ices and rock. Winds on the planet can reach up to 900 kmph (560 mph). Uranus sits at almost a 90 degree angle, putting its poles where most planets' equator is.

- 18.3 AU to 20.1 AU from Sol.
- Equatorial diameter: 51,118 km, Polar diameter: 49,946 km.
- 27 confirmed natural satellites; 6 have retrograde orbits
    - Miranda - 480×468.4×465.8 km
    - Ariel - 1162.2×1155.8×1155.4 km
    - Umbriel - 1169.4 km
    - Titania - 1577.8 km
    - Oberon - 1522.8 km

Neptune

In contrast to the relatively featureless atmosphere of Uranus, Neptune's atmosphere is notable for its active and visible weather patterns. At the time of the 1989 *Voyager 2* flyby, for example, the planet's southern hemisphere possessed a Great Dark Spot comparable to the Great Red Spot on Jupiter. These weather patterns are driven by the strongest sustained winds of any planet in the Solar System, with recorded wind speeds as high as 2,100 kmph. Because of its great distance from the Sun, Neptune's outer atmosphere is one of the coldest places in the Solar System, with temperatures at its cloud tops approaching −218 °C (55 K). Temperatures at the planet's center, however, are approximately 5,400 K (5,000 °C). Neptune has a faint and fragmented ring system, which may have been detected during the 1960s but was only indisputably confirmed in 1989 by *Voyager 2*.



- Equatorial diameter: 49,528 km, Polar diameter: 48,681 km.
- Has wind speeds up to 12,000 mph. Atmosphere is mostly hydrogen, helium and methane.
- 29.810 AU to 30.327 AU from Sol.
- 13 confirmed natural satellites; 5 have retrograde orbits
    - Proteus - 436 x 416 x 402 Km
        - Proteus is one of the darkest objects in the solar system, as dark as soot; it reflects only 6 percent of the sunlight that strikes it
        - Proteus is very cratered showing no sign of any geological modification. It is also irregularly shaped; scientists believe Proteus is about as large as a body of its density can be without being pulled into a spherical shape by its own gravity
    - Triton - 2706.8±1.8 km; has a retrograde orbit
        - Triton is unique among all large moons in the solar system for its retrograde orbit around the planet (i.e., it orbits in a direction opposite to the planet's rotation). Triton's axis of rotation is also unusual, tilted 157 degrees with respect to Neptune's axis, and 130 degrees with respect to Neptune's orbit. This means Triton's rotational axis points within 40 degrees of the Sun twice per Neptunian year, much like Uranus'. As Neptune orbits the Sun, Triton's polar regions take turns facing the Sun, probably resulting in radical seasonal changes as one pole then the other moves into the sunlight. During the Voyager 2 encounter, Triton's south pole was facing the Sun. Almost the entire southern hemisphere was covered with an "ice cap" of frozen nitrogen and methane. The average surface temperature is -390 degrees F.
    - Neried - 340 km
        - Its orbit averages 5,513,400 km in radius, but is highly eccentric and varies from 1,353,600 to 9,623,700 kilometers. This is the most highly eccentric orbit of any known satellite in the solar system. The unusual Nereidian orbit suggests that it may be a captured asteroid or Kuiper belt object, or possibly that it was

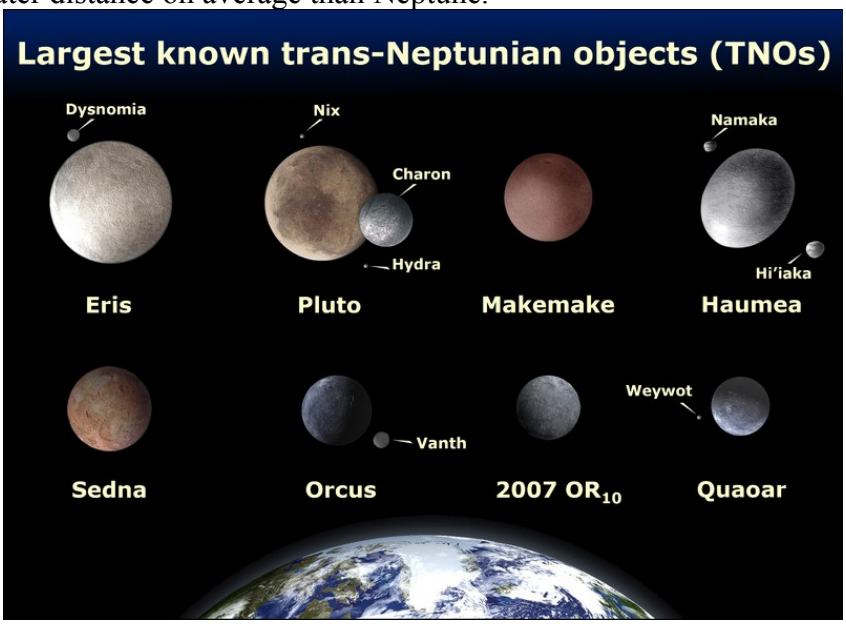
perturbed during the capture of Neptune's largest moon Triton. Very little else is known of Nereid

Neptune Trojan Asteroids

- Neptune-Sun Lagrangial Points
  - L_4 point
    - 2001 QR_{322} - orbits ahead of Neptune
    - 2004 UP_{10} - has the same orbital period as Neptune and orbits at the Neptune-Sun L_4 Lagrangian point about 60º ahead of Neptune

Trans-Neptunian Objects

A trans-Neptunian object (TNO) is any object in the solar system which orbits the sun at a greater distance on average than Neptune.



- Kuiper Belt - 30 to 50 AU from Sol
  - The Kuiper Belt is an area extending from within the orbit of Neptune (at 30 AU) to 50 AU from Sol, at inclinations consistent with the ecliptic. Objects within the Kuiper Belt are referred to as trans-Neptunian objects (a type of minor planet). They are sometimes also called asteroids.
  - Over 800 Kuiper belt objects (KBOs) have been discovered. KBOs are by (current) definition limited to 30-44 AU from the Sun.
- Plutino Objects
  - Plutino are Pluto-like objects, insofar as it has the same relative orbit as Pluto. These orbits are stabilized by an orbital resonance with Neptune, similar to Pluto's 3:2 orbital resonance. This means that Plutinos complete 2 orbits around the Sun in the time it takes Neptune to complete 3 orbits. Plutinos form the inner part of the Kuiper belt
  - Pluto
    - 29.7 AU to 49.3 AU from Sol
    - Diameter: 2,390 km

        - 3 confirmed natural satellites; Charon possibly forming a binary planet as it appears they orbit together around their mutual point of gravity
            - Charon - Diameter is 1,205 km
                - Due to the unusually small difference in size between it and Pluto, Pluto and Charon are sometimes considered to be a double planet. They are also sometimes thought of as not a planet and a satellite, but as the first two Trans-Neptunian objects
            - S/2005 P 1 - estimated diameter: 110 to 160 km
            - S/2005 P 2 - estimated diameter: 100 and 140 km
    - Ruins of South Ataria Isle
        - When the SDF-1 made the spacefold at the start of SWI, it took with it and deposited South Ataria Island and a sizeable amount of the surrounding Pacific waters with it, depositing them 'near Pluto.' It is most likely slowly spreading over a larger area due to events that occurred immediately after its arrival and subsequent interactions with gravity fields and Solar wind passing through the area. It is the author's opinion that the area looks more like an icy 'smudge' (perhaps occasionally being mistaken for a comet) in space.
    - 28978 Ixion - diameter of 822 km; 30.0 AU to 49.07 AU from Sol
    - 90482 Orcus - Dimensions 840 - 1880 km; 30.861 AU to 48.071 AU from Sol
        - 1 confirmed natural satellite named Vanth; possibly as much as 1/3 the size of Orcus
    - 38083 Rhadamanthus - 33.19 AU to 45.28 AU from Sol
    - (47171) 1999 TC_{36} - ?? Km; 30.5454 AU to 47.9106 AU from Sol
    - 2003 EL_{61} Haumea - 1,960 km × 1,518 km × 996 km to 2,500 km × 1,080 km × 8,60 km; 35.155 AU to 51.524 AU from Sol
        - The rotation period of 2003 EL_{61} is much faster than any other object of its size, less than four hours. The fast rotation has caused the object to become highly oblate: it is twice as long as wide and shorter still in height. Spiraling-in effect of 2003 EL61 and its moon may have caused the speeding up of the rotation. The spectra of 2003 EL_{61}, which show strong water ice features similar to what is seen on the surface of Pluto's moon Charon. Methane ice has been detected on the surface of 2003 EL_{61}, which means it has never been very close to the Sun. Its reflectivity is reported being “almost that of pure snow”
        - 2 confirmed natural satellites
            - Hi'iaka, at first nicknamed "Rudolph" by the Caltech team, was discovered January 26, 2005. It is the outer and, at roughly 310 km in diameter, the larger and brighter of the two, and orbits Haumea in a nearly circular path every

49 days. Strong absorption features at 1.5 and 2 micrometers in the infrared spectrum are consistent with nearly pure crystalline water ice covering much of the surface. The unusual spectrum, along with similar absorption lines on Haumea, led Brown and colleagues to conclude that capture was an unlikely model for the system's formation, and that the Haumean moons must be fragments of Haumea itself.

- Namaka, the smaller, inner satellite of Haumea, was discovered on June 30, 2005, and nicknamed "Blitzen". It is a tenth the mass of Hi'iaka, orbits Haumea in 18 days in a highly elliptical, non-Keplerian orbit, and as of 2008 is inclined 13° from the larger moon, which perturbs its orbit. The relatively large eccentricities together with the mutual inclination of the orbits of the satellites are unexpected as they should have been damped by the tidal effects. A relatively recent passage by a (3:1) resonance might explain the current excited orbits of the Haumea moons.

- Twotino
  - While a Plutino completes 2 orbits around the Sun in the time it takes Neptune to complete 3 orbits, a Twotino makes 1 orbit around the Sun in the time it takes Neptune to complete 2 orbits. Use of the term "Twotino" is relatively rare compared with the term "Plutino", and there are many more Plutinos
  - Some known Twotinos: 1996 TR66, 1998 SM165, 1997 SZ10, 1999 RB216, 2000 JG81
- Cubewano
  - A cubewano is any substantial Kuiper belt object, orbiting beyond about 41 AU and not controlled by resonances with the outer planets
  - (15760) 1992 QB_1 - Dimensions: ???; 40.8754 AU to 46.5925 AU from Sol
  - (19521) Chaos - Dimensions: ???; 40.9264 AU to 50.5041 AU from Sol
  - (50000) Quaoar - Diameter: 989 to 1346 km; 41.914 AU to 44.896 AU from Sol
  - (20000) Varuna - Diameter: about 1060 Km; 40.915 AU to 45.335 AU from Sol
    - Little is known about it. It has a rotational period of approximately 3.17 hours (or 6.34 hours, depending on whether the light curve is single or double-peaked). It has a density of approximately 1 g/cm? (as dense as water), which implies that it may not be a fully solid body (Jewitt & Sheppard, 2002). The surface is darker than the surface of Pluto indicating it is largely devoid of ice.
  - 2005 FY_9 Makemake - Initial estimates gave a diameter of 50% to 75% that of Pluto. It is similar in size to 2003 EL61, although slightly brighter; 38.71 AU to 52.57 AU from Sol. Originally nicknamed "Easterbunny".

    - (53311) Deucalion - Dimensions: ???; 41.5791 AU to 44.3683 AU from Sol
    - (19308) 1996 TO_{66} - ?? Km; 37.9131 AU to 48.3595 AU from Sol
    - 1998 WW_{31} - ?? Km; 40.7517 AU to 48.3996 AU from Sol
        - It forms a binary system with another object with the designation S/2000 (1998 WW_{31}) 1; the combined system was the first trans-Neptunian binary to be discovered.
- Damocloid Asteroid
    - Damocloids are asteroids such as 5335 *Damocles* and *1996 PW* that have long-period highly eccentric orbits typical of periodic comets such as Comet Halley, but without showing a cometary coma or tail.
    - Damocloids are believed to be nuclei of Halley-type comets that have lost all their volatile materials due to outgassing. Such comets are believed to originate from the Oort cloud. Another strong indication of cometary origin is the fact that some Damocloids have retrograde orbits, unlike any other asteroids.
    - As of late 2005, 25 were known.
    - Their average radius is 8 Km.
    - The albedos of four Damocloids have been measured, and they are among the darkest objects known in the Solar system. Damocloids are reddish in color, but not as red as many Kuiper belt objects or Centaurs.
- Kuiper Gap (aka Kuiper Cliff)
    - around 50 AU from Sol
    - The outer boundary of the Kuiper belt is not defined arbitrarily; rather, there appears to be a real and fairly sharp dropoff in objects beyond a certain distance. The cause for this remains a mystery; one possible explanation would be a hypothetical Earth-sized or Mars-sized object sweeping away debris.

Scattered Disc

The scattered disc (or scattered disk) is a distant region of our solar system, thinly populated by icy planetoids known as scattered disk objects (SDOs). The innermost portion of the scattered disc overlaps with the Kuiper belt, but its outer limits extend much farther away from the sun and above and below the ecliptic than the belt proper.

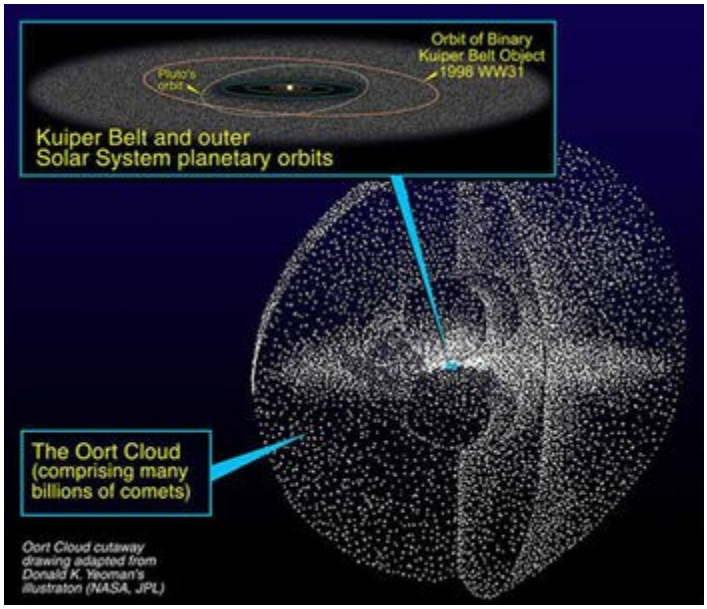
While the Kuiper belt is a relatively "round" and "flat" doughnut of space extending from about 30 AU to 44 AU with its member-objects locked in autonomously circular orbits (cubewanos) or mildly-elliptical resonant orbits (plutinos and twotinos), the scattered disc is by comparison a much more erratic milieu. SDOs can often, as in the case of 2003 UB313, travel almost as great a "vertical" distance they do relative to what has come to be defined as "horizontal".

Although the TNO 90377 Sedna is officially considered an SDO by the MPC, its suggested that because its perihelion distance of 76 AU is too distant to be affected by the gravitational attraction of the outer planets it should be considered an inner Oort cloud object rather than a member of the scattered disk. 2000 CR105, which was discovered before Sedna, may also be an inner Oort cloud object or (more likely) a transitional object between the scattered disc and the inner Oort cloud.

- 30 to 50 AU from Sol
- 2003 UB_{313} Eris
    - diameter at least 2390 km
    - 38.2 AU to 97.610 AU from Sol.
    - The object has already been dubbed the tenth planet by the discoverers, NASA, and some media outlets; the 2006 IAU defined Eris as a dwarf planet.
    - Eris also has the nicknames of Xena and Lila.
    - 1 confirmed natural satellite
        - S/2005 (2003 UB_{313}) 1 Dysnomia
            - Dysnomia has the nickname of Gabrielle
- (15874) 1996 TL_{66} - less than 958 km (350 km?); 35.029 AU to 130.774 AU from Sol
- (26375) 1999 DE_9 - ?? Km; 32.3166 AU to 79.7710 AU from Sol
- (87269) 2000 OO_{67} - ?? Km
    - This is notable for its highly eccentric orbit: 21 AU to over 1,000 AU from the sun, crossing the orbit of Neptune at closest approach.
    - It is believed this object is composed of rock and ices.
- 2000 CR_{105} - dimensions: ??? Km; average distance of 224 AU from Sol
- (90377) 2003 VB_{12} Sedna - 1200 to 1600 Km; 76.361 AU to 960.78 AU from Sol

Oort Cloud

The Oort cloud (sometimes called the Opik-Oort Cloud) is a postulated spherical cloud of comets situated about 50,000 to 100,000 AU from the Sun. This is approximately 1000 times the distance from the Sun to Pluto or roughly one light year, almost a quarter of the distance from the Sun to Proxima Centauri, the star nearest the Sun.



The Oort cloud would have its inner disk at the ecliptic from the Kuiper belt. Although no direct observations have been made of such a cloud, it is believed to be the

source of most or all comets entering the inner solar system (some short-period comets may come from the Kuiper belt), based on observations of the orbits of comets.

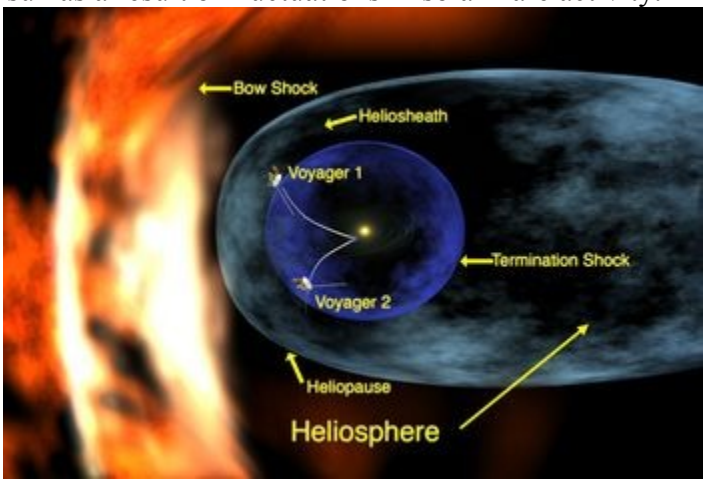
The Oort cloud is a remnant of the original nebula that collapsed to form the Sun and planets five billion years ago, and is loosely bound to the solar system. The most widely-accepted hypothesis of its formation is that the Oort cloud's objects initially formed much closer to the Sun as part of the same process that formed the planets and asteroids, but that gravitational interaction with young gas giants such as Jupiter ejected them into extremely long elliptical or parabolic orbits. This process also served to scatter the objects out of the ecliptic plane, explaining the cloud's spherical distribution. While on the distant outer regions of these orbits, gravitational interaction with nearby stars further modified their orbits to make them more circular.

It is thought that other stars are likely to possess Oort clouds of their own, and that the outer edges of two nearby stars' Oort clouds may sometimes overlap, causing the occasional intrusion of a comet into the inner solar system. The star with the greatest possibility of perturbing the Oort cloud in the next 10 million years is Gliese 710.

- Inner Oort Cloud
    - 90377 Sedna - estimated diameter 1180 to 1800 Km; 76.032 AU to 928.048 AU

Termination Shock

About 100 AU from Sol. The termination shock boundary fluctuates in its distance from the sun as a result of fluctuations in solar flare activity.



Heliosheath

The heliosheath is the zone between the termination shock and the heliopause at the outer border of the solar system. It lies along the edge of the heliosphere, a "bubble" caused by solar winds.

- 80 to 100 AU from Sol.

Heliopause

- The heliopause is the boundary where the Sun's solar wind is stopped by the Interstellar medium.

- The solar wind blows a "bubble" known as the heliosphere in the interstellar medium (the rarefied hydrogen and helium gas that permeates the galaxy). The outer border of this "bubble" is where the solar wind's strength is no longer great enough to push back the interstellar medium. This is known as the heliopause, and is often considered to be the outer border of the solar system.
- Outside the heliopause, the interaction between the interstellar medium and the heliopause produces the bow shock, a turbulent region in front of the Sun's progress through the interstellar medium.
- The distance to the heliopause is not precisely known. It is probably much smaller on the side of the solar system facing the orbital motion through the galaxy. It may also vary depending on the current velocity of the solar wind and the local density of the interstellar medium.
- When particles emitted by the sun bump into the interstellar ones, they slow down while releasing energy (warming up). Many particles accumulate in and around the heliopause, highly energized by their negative acceleration, creating a shock wave. An alternative definition is that the heliopause is the magnetopause between the solar system's magnetosphere and the galaxy's plasma currents.

Chapter 13 – Building a Star System

This chapter provides information for creating new star systems for a Macross 2050 campaign. At first this all seem overwhelming, as some of it references some pretty sophisticated mathematics and scientific theories. Most of it will be simplified enough to create a star system without spending months in calculations.

You may be wondering why you need to know all of this college level information. Really you don't; but it is useful for making star systems that make sense, and it's quite interesting to read. Other science fiction RPGs, there are random generation charts in which you can come up with results that most likely could never exist. In a science fantasy game such as Rifts where you can just say "some ancient deity did it", that is fine. However, this game attempts to keep as much scientific fact as possible. Thus, this will be a rather long and complex chapter.

The Universe

Before one can take a look at specific stars and planets, one must take a look at the big picture of the universe. This will be fairly shorthand, and will use the generally accepted theories.

Big Bang & Formation

This is really a misnomer, as it was not big, and without air there was no bang. Theory says that since the universe is steadily expanding, then at one point of time all that exists was in one point. Mathematical calculations place this at 14.7 billion years ago. At this point in time, all matter and energy of the universe was compacted smaller than the smallest part of an atom. Then something happened and boom, it all began to expand. Measurements of background radiation in space show uniform heat, which is attributed to a super-fast expansion burst during the first few milliseconds of existence, before the four major forces of physics (electromagnetic, gravitation, weak nuclear and strong nuclear) split away from one primal force.

Approximately one second after the big bang, the first protons and neutrons form. After 3 minutes up to about 20 minutes, the first hydrogen atoms form. Somewhere from 240,000 years to 310,000 years after the big bang, helium begins to form. From around 500 million years to 1 billion years after, the formation of Population III stars form from the hydrogen, helium and trace amounts of lithium 4. These stars are super-massive and convert their fuel at astonishing rates, only to go supernova. From those remaining gasses, the Population II stars form. From these new stars, all but the most unstable elements are eventually formed. Eventually these stars also go supernova and from their remains form the Population I stars and the planets.

Endgame

Eventually the universe will die out. To explain this, one needs to understand the concept of dark energy. While this is currently not well understood, it is believed to comprise about 74% of the mass-energy of the entire universe and fills the void between galaxies and star clusters homogeneously.

Big Freeze - This is considered to be the most likely outcome. Around 10^{14} years from now, all of the stars burn out and no more are created. The universe becomes a cold dark place, with the last vestiges of life huddling around dim brown dwarf stars. Eventually all matter will collapse into low-energy radiation.

Big Rip - By this theory, if dark matter continues to expand without limit, around 200 million years or more into the future all gravitational bonds will be torn apart. Galaxies fall apart, solar systems fall apart, atoms fall apart. Everything will be torn into their subatomic particles, and even those will be pulled apart.

Big Crunch - This theory says that eventually around 100 million years or more from now, everything will be pulled back into the center where it all began, forcing all matter and energy back into its pre big bang state. Most scientists speculate this outcome as being highly unlikely.

Vacuum Metainstability Event - This complex quantum theory, boiled down and simplified greatly, suggests if the universe is in a false vacuum state and quantum tunnels to a lower energy state, all matter will simply flash out of existence with no warning. Scary.

Galaxies

While Macross is contained within just a single galaxy, it could be possible to explore other galaxies as well. With the amount of superscience used by the Protoculture, it would not be unreasonable that they discovered some form of practical travel across the void between galaxies and may have left the Milky Way galaxy for a neighboring galaxy after the Protodeviln were defeated (not like that scenario *never* happens in sci-fi). Given that the Vajra are an intergalactic race, there is at least proof of life in other galaxies.

Definition of a galaxy

A galaxy is a massive, gravitationally bound system that consists of stars, an interstellar medium of gas and dust, and dark matter. Typical galaxies range from dwarfs with as few as ten million (10^7) stars up to giants with one trillion (10^{12}) stars, all orbiting a common center of gravity. Galaxies can also contain a large number of multiple star systems and star clusters as well as various types of interstellar clouds.

Historically, galaxies have been categorized according to their apparent shape (usually referred to as their visual morphology). A common form is the elliptical galaxy, which has an ellipse-shaped light profile. Spiral galaxies are disk-shaped assemblages with curving dusty arms. Galaxies with irregular or unusual shapes are known as peculiar galaxies, and typically result from disruption by the gravitational pull of neighboring galaxies. Such interactions between nearby galaxies, which may ultimately result in a galaxy merger, may induce episodes of significantly increased star formation, producing what is called a starburst galaxy. Small galaxies which lack a coherent structure may also be referred to as irregular galaxies.

There are probably more than a hundred billion (1011) galaxies in the observable universe. Most galaxies are a thousand to a hundred thousand parsecs in diameter and are usually separated from one another by distances on the order of millions of parsecs (or megaparsecs). Intergalactic space, the space between galaxies, is filled with a tenuous gas with an average density less than one atom per cubic meter. The majority of galaxies are organized into a hierarchy of associations called clusters, which, in turn, can form larger groups called superclusters. These larger structures are generally arranged into sheets and filaments, which surround immense voids in the universe.

Although theoretical, dark matter appears to account for around 90% of the mass of most galaxies. But the nature of these unseen components is not well understood. There is also some evidence that supermassive black holes, with a mass ranging from 10^5 and 10^{10} (hundreds of thousands and tens of billions) of solar masses, may exist at the center of many, if not all, galaxies. These massive objects are believed to be the primary cause of active galactic nuclei found at the core of some galaxies. The Milky Way galaxy appears to harbor at least one such object within its nucleus.

Travel between galaxies

The biggest problem with dealing with other galaxies is that they are thousands or millions of light years apart, making travel even at light speed very impractical. As an example from another popular science fiction series, Stargate Atlantis, the lost city of Atlantis is located in a star system in the Pegasus Dwarf Irregular Galaxy (PDIG) which is approximately 3 million light years (mly) away from the Milky Way. The ancients who built the city dwelt there millions of years ago when they fought with the Wraith. In one episode, it stated an Ancient battleship had traveled between the Milky Way and Pegasus galaxies at 99.9% of the speed of light (0.999). This trip seemed like 12 years to them (due to time relativity) while millions of years passed around them (Rodney states it would take at least a million years to reach the Milky Way at 100% light speed). This is scientifically sound since their velocity was just under 1 light year per year traveling 3 mly for a travel time of approximately 3,030,000 years. Furthermore, traveling so close to lightspeed slows the aging of all aboard the ship.

The Macross saga has better FTL capabilities. All Protoculture-based capital ships can travel at 1 LY every 6 minutes via space folding, and averaging 0.20 of lightspeed (61,050 km per second) via sublight drives. This means it would still take around 34 years to reach the Pegasus galaxy (approximately 12,500 days). Unfortunately, the further you attempt to travel with a single space fold increases the likelihood of accident, not to mention the amount of energy required increases geometrically.

Galaxy Formation and Evolution

The study of galactic formation and evolution attempts to answer questions regarding how galaxies formed and their evolutionary path over the history of the universe. Some theories on this field have now become widely accepted, but it is still an active area of study in astrophysics.

Formation

Current cosmological models of the early Universe are based upon the Big Bang theory. About 300,000 years after this event, atoms of hydrogen and helium began to form, an event termed recombination. Nearly all the hydrogen was neutral (non-ionized), and readily absorbed light, and no stars had yet formed. As a result this period has been called the "Dark Ages". It was from density fluctuations (or anisotropic irregularities) in this primordial matter that larger structures began to appear. As a result, masses of baryonic matter started to condense within cold dark matter halos. These primordial structures would eventually become the galaxies we see today.

Evidence for the early appearance of galaxies was found in 2006, when it was discovered that the galaxy IOK-1 has an unusually high redshift of 6.96, making it the most distant galaxy yet seen. While some scientists have claimed other objects (such as Abell 1835 IR1916) have higher redshifts (and therefore are seen in an earlier stage of the Universe's evolution), IOK-1's age and composition have been more reliably established. The existence of such early protogalaxies suggests that they must have grown in the so-called "Dark Ages".

The detailed process by which such early galaxy formation occurred is a major open question in astronomy. Theories may be divided into two categories: top-down and bottom-up. In top-down theories (such as the Eggen–Lynden-Bell–Sandage [ELS] model), protogalaxies form in a large-scale simultaneous collapse lasting about one hundred million years. In bottom-up theories (such as the Searle-Zinn [SZ] model), small structures such as globular clusters form first, and then a number of such bodies accrete to form a larger galaxy. Modern theories must be modified to account for the probable presence of large dark matter halos.

Once protogalaxies began to form and contract, the first halo stars (called Population III stars) appeared within them. These were composed almost entirely of Hydrogen and Helium, and may have been massive. If so, these huge stars would have quickly consumed their supply of fuel and became supernovae, releasing heavy elements into the interstellar medium. This first generation of stars re-ionized the surrounding neutral hydrogen, creating expanding bubbles of space through which light could readily travel.

Evolution

Within a billion years of a galaxy's formation, key structures begin to appear. Globular clusters, the central supermassive black hole, and a galactic bulge of metal-poor Population II stars form. The creation of a supermassive black hole appears to play a key role in actively regulating the growth of galaxies by limiting the total amount of additional matter added.

[left] I Zwicky 18 is a recently-formed galaxy that may still be producing its first generation of stars.[60] NASA/ESA Hubble Space Telescope image.

During the following two billion years, the accumulated matter settles into a galactic disk. A galaxy will continue to absorb infalling material from high velocity clouds and dwarf galaxies throughout its life. This matter is mostly hydrogen and helium. The cycle of stellar birth and death slowly increases the abundance of heavy elements, eventually allowing the formation of planets.

The evolution of galaxies can be significantly affected by interactions and collisions. Mergers of galaxies were common during the early epoch, and the majority of galaxies were peculiar in morphology. Given the distances between the stars, the great majority of stellar systems in colliding galaxies will be unaffected. However, gravitational stripping of the interstellar gas and dust that makes up the spiral arms produces a long train of stars, similar to that seen in NGC 250 or the Antennae Galaxies.

As an example of such an interaction, the Milky Way galaxy and the nearby Andromeda Galaxy are moving toward each other at about 130 km/s, and, depending upon the lateral movements, the two may collide in about five to six billion years. Although the Milky Way has never collided with a galaxy as large as Andromeda before, evidence of past collisions of the Milky Way with smaller dwarf galaxies is increasing.

Such large scale interactions are unlikely. As time passes, mergers of two systems of equal size become less common. Most bright galaxies have remained fundamentally unchanged for the last few billion years, and the net rate of star formation also peaked approximately five billion years ago.

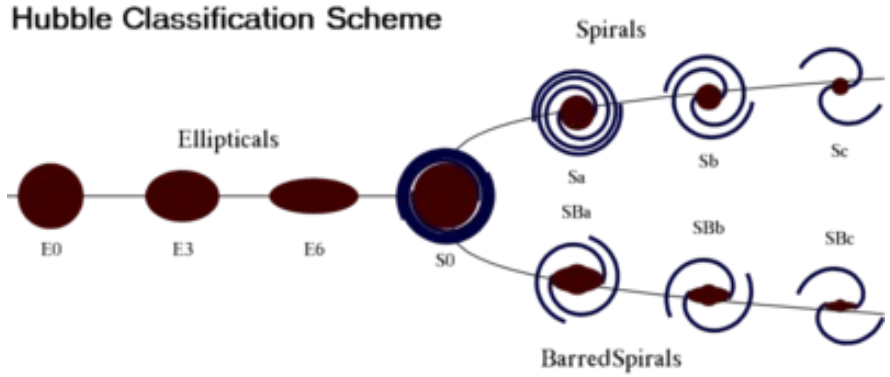
Future trends

At present, most star formation occurs in smaller galaxies where cool gas is not so depleted. Spiral galaxies, like the Milky Way, only produce new generations of stars as long as they have dense molecular clouds of interstellar hydrogen in their spiral arms. Elliptical galaxies are already largely devoid of this gas and so form no new stars. The supply of star-forming material is finite; once stars have converted the available supply of hydrogen into heavier elements, new star formation will come to an end.

The current era of star formation is expected to continue for up to one hundred billion years, and then the "stellar age" will wind down after about ten trillion to one hundred trillion years (1013-1014 years), as the smallest, longest-lived stars in our astrosphere, tiny red dwarfs, begin to fade. At the end of the stellar age galaxies will be composed of compact objects: brown dwarfs, black dwarfs, cooling white dwarfs, neutron stars, and black holes. Eventually, as a result of gravitational relaxation, all stars will either fall into central supermassive black holes or be flung into intergalactic space as a result of collisions.

Galaxy Morphology

The Hubble sequence is a classification of galaxy types developed by Edwin Hubble in 1925. It is also called the tuning-fork diagram due to the shape of its graphical representation.



Tuning-fork style diagram of the Hubble sequence

The Hubble "tuning fork" diagram starts from the left with elliptical galaxies as its base. Elliptical galaxies can be named from E0 to E7. E stands for elliptical while the number indicates how oval-shaped the ellipse is with 0 being ball shape (in other words, a giant globular cluster) to 7 being discus shape. Technically speaking, the number is ten times the ellipticity. For example, an E7 galaxy has an ellipticity of 0.7.

After the elliptical galaxies the diagram splits into two branches. The upper branch covers spiral galaxies. It starts off with S0, also called lenticular galaxies. The "S" means spiral, the "0" means no arms, and the subscript number indicates how heavily a stripe is absorbed out of the image of the galaxy by dust in the galactic disc. On the same branch are the next 3 types which all have spiral arms. The "S" here also means spiral, but the lower case letter after it tell how wound up the arms are. They range from "a" to "d" having the following meanings:

- Sa - tightly-wound, smooth arms, and a bright central disc
- Sb - better defined spiral arms than Sa
- Sc - much more loosely wound spiral arms than Sb
- Sd - very loose arms, most of the luminosity is in the arms and not the disc

The lower branch of the diagram covers barred spiral galaxies given the symbol "SB". This branch starts with SBO galaxies which is followed by a subscript number that indicates how heavily defined the bar is. After that the branch continues with the SB galaxies which have lower case letters after them that indicates how heavily defined the bar is. They range from "a" to "c" having the following meanings:

- SBa - a bright center and tight spirals
- SBb - better defined arms than SBa galaxy and are more loosely wound
- SBc - even looser arms, and a much dimmer central portion of the galaxy

The Milky Way Galaxy is currently believed to be an SBb galaxy.

Contrary to popular opinion, the galactic tuning fork has nothing to do with the evolution of galaxies. For example, S0 galaxies do not split into two groups, one which turns into regular spirals and one which becomes barred. Likewise, spiral or barred-spiral galaxies do not evolve into ellipticals. However, there are reasons to believe that elliptical galaxies in general are older than spiral galaxies. For instance, elliptical E galaxies appear redder than S galaxies, which indicates that they consist of older, redder stars and stellar clusters. The fact that S galaxies usually seem bluer and brighter hints at star formation. Since stellar formation requires dust clouds to collapse gravitationally, we may think S galaxies to be younger than E galaxies where all necessary ingredients for star formation has already 'been used up'. Yet it needs to be mentioned that also through intergalactical interaction star formation (Balmer lines) is frequently observed. The all-encompassing evolutionary diagram of galaxies remains one of the unresolved challenges of astronomy today.

Galaxy types are divided as follows:

1) An elliptical galaxy (E0-7) has an ellipsoidal form, with a fairly even distribution of stars throughout. The number is related to eccentricity but is defined by ten times the galaxy's ellipticity, which is mainly used in astronomy, i.e. $n = 10\left(1 - \frac{b}{a}\right)$ where b is the short axis and a is the long axis. E0 galaxies are nearly round, while E7 are greatly flattened. The number indicates only how the galaxy appears on the sky, not its true geometry.
2) A lenticular galaxy (S0 and SB0) appears to have a disk-like structure with a central spherical bulge projecting from it, and does not show any spiral structure.
3) A spiral galaxy (Sa-d) has a central bulge and an outlying disk containing spiral arms. The arms are centered around the bulge, and vary from tightly wound (Sa) to very loose (Sc and Sd). The latter also have less pronounced central bulges.
4) A barred spiral galaxy (SBa-d) has a similar sort of spiral structure to spiral galaxies, but instead of emanating from the bulge, the arms project out from the ends of a "bar" running through the bulge, like ribbons on either end of a baton. Again, SBa to SBd refer to how "tightly wound" these arms are.
5) An irregular galaxy (Irr) can be of type Irr-I, which shows spiral structure but is deformed in some way, and Irr-II for any other galaxy that does not fit into another category.

Known Properties of Galaxies

Galaxy Type	Mass (Solar Masses)	Luminosity (Solar Luminosity)	Diameter (kpc)	Stellar Populations	Percentage of Observed Galaxies
Spiral / Barred Spiral	109 to 1011	108 to 1010	5-250	disk: Population I halo: Population II	77%

Elliptical	105 to 1013	105 to 1011	1-205	Population II	20%
Irregular	108 to 1010	107 to 109	1-10	Population I	3%

Hubble based his classification on photographs of the galaxies through the telescopes of the time. He originally believed that elliptical galaxies were an early form, which might have later evolved into spirals; our current understanding suggests that the situation is roughly opposite, however, this early belief left its imprint in the astronomers' jargon, who still speak of "early type" or "late type" galaxies according to whether a galaxy's type appears to the left or to the right in the diagram.

More modern observations of galaxies have given us the following information about these types:

- Elliptical galaxies are generally fairly low in gas and dust, and are composed mostly of older stars.
- Spiral galaxies generally have plentiful supplies of gas and dust, and have a broad mix of older and younger stars.
- Irregular galaxies are fairly rich in gas, dust, and young stars.

From this, astronomers have constructed a theory of galaxy evolution which suggests that ellipticals are, in fact, the result of collisions between spiral and/or irregular galaxies, which strip out much of the gas and dust and randomize the orbits of the stars.

de Vaucouleurs

There is an extension to the Hubble sequence that widely used: the de Vaucouleurs extensions. The distinction between the de Vaucouleurs and Hubble classification systems lies primarily with spiral galaxies. While the Hubble type describes spiral galaxies based upon the two criteria of tightness of spiral and barredness, de Vaucouleurs adds a third descriptor, internal ring.

- Spiralness: galaxies range from E, through S0, through the other spirals, to Im.
- Barredness: galaxies are described as being A (ordinary), B (barred), or AB (intermediate).
- Ringedness: galaxies are described as being s-shaped (no ring), r-shaped (ring), or sr (intermediate).

Therefore, a galaxy may be described as being SAB(rs)c - Sc spiral, between barred and ordinary, and between ringed and no ring.

Visually, the de Vaucouleurs system is often represented in three dimensions, with spiralness on the x-axis, barredness on the y-axis, and ringedness on the z-axis. A cross-section of one spiralness (eg: Sb) will yield a representation in two dimensions with ringedness on the x-axis and barredness on the y-axis.

Disc Galaxy

Disc galaxies are galaxies which have *discs*, a flattened circular volume of stars. These galaxies may, or may not include a central non-disc-like region (central bulge). Disc galaxies include *spiral galaxies* (barred, unbarred and intermediate barred) and *lenticular galaxies*. Spiral galaxies have very little random movement, being dominated by rotational energy.

Barred or Unbarred

Barred galaxies have a band of bright stars extending from opposite sides of the galactic core with the spiral arms connecting to the ends of the bars. Unbarred galaxies lack this band, with the spiral arms connecting directly to the galactic core itself. An intermediate barred galaxy is somewhere between these two classifications.

Elliptical Galaxy

Elliptical galaxies differ from spiral galaxies in several manners:

- The motion of stars is dominated by random motion, unlike spiral galaxies, which have very little random motion and are dominated by rotation.
- Very little interstellar matter, few young stars, and few open star clusters
- Consist of old, so-called Population II stars

Larger elliptical galaxies typically have a system of globular clusters, indicating an old population.

This traditional portrait of elliptical galaxies paints them as galaxies where star formation has finished after the initial burst, leaving them to shine with only their aging stars. Very little star formation is thought to happen. In general, they appear yellow-red, which is in contrast to the distinct blue tinge of a typical spiral galaxy, a color emanating largely from the young, hot stars in its spiral arms.

There is a wide range in size and mass for elliptical galaxies: as small as a tenth of a kiloparsec to over 100 kiloparsecs, and from 107 to nearly 1013 solar masses. The smallest, the Dwarf elliptical galaxies, may be no larger than a typical globular cluster, but contain a considerable amount of dark matter not present in clusters. Most of these small galaxies may not be related to other ellipticals. The single largest known galaxy, M87 (which also goes by the NGC number 4486), is an elliptical. This range is much broader for this galaxy type than for any other.

It was once thought that the shape of ellipticals varied from spherical to highly elongated. The Hubble classification of elliptical galaxies ranges from E0 for those that are most spherical, to E7, which are long and thin. It is now recognized that the vast majority of ellipticals are of middling thinness, and that the Hubble classifications are a result of the angle with which the galaxy is observed.

There are two physical types of ellipticals; the "boxy" giant ellipticals, whose shapes result from random motion which is greater in some directions than in others (anisotropic random motion), and the "disk" normal and low luminosity ellipticals, which have nearly isotropic random velocities but are flattened due to rotation.

Dwarf elliptical galaxies are probably not true ellipticals at all; they have properties that are similar to those of irregulars and late spiral-type galaxies. Many astronomers now refer to them as "dwarf spheroidals" in recognition of this (note that this is still a topic of some controversy).

Ellipticals and the bulges of disk galaxies have similar properties, and are generally regarded as the same physical phenomenon

Elliptical galaxies tend to lie in the cores of galaxy clusters and in compact groups of galaxies.

Some recent observations have found young, blue star clusters inside a few elliptical galaxies, along with other structures that can be explained by galaxy mergers. Current thinking is that an elliptical galaxy is the result of a long process where two galaxies of comparable mass, of any type, collide and merge.

Such major galaxy mergers are thought to have been common at early times, but may carry on more infrequently today. Minor galaxy mergers involve two galaxies of very different masses, and are not limited to giant ellipticals. For example, our own Milky Way galaxy is known to be "digesting" a couple of small galaxies right now.

Lenticular Galaxy

A lenticular galaxy is a type of galaxy which is an intermediate between an elliptical galaxy and a spiral galaxy in the Hubble sequence classification scheme. Lenticular galaxies are disc galaxies (like spiral galaxies) which have used up or lost their interstellar matter (like elliptical galaxies). Because of their ill-defined spiral arms, if they are inclined face-on it is often difficult to distinguish between them and elliptical galaxies. Hubble classification of lenticulars are S0, SB0, E8

Lenticular galaxies may be barred or unbarred like a spiral galaxy.

Irregular Galaxy

An irregular galaxy is a galaxy that does not fall into the Hubble classification for galaxies. These are galaxies that feature neither spiral nor elliptical morphology. They are often chaotic in appearance, with neither a nuclear bulge nor any trace of spiral arm structure. Collectively they are thought to make up about a quarter of all galaxies. Most irregular galaxies were once spiral or elliptical galaxies but were deformed by gravitational action.

There are two major Hubble types of irregular galaxies:

- An Irr-I galaxy (Irr I) is an irregular galaxy that features some structure but not enough to place it cleanly into the Hubble sequence. de Vaucouleurs subtypes this into galaxies that have some spiral structure Sm, and those that do not Im.
- An Irr-II galaxy (Irr II) is an irregular galaxy that does not appear to feature any structure that can place it into the Hubble sequence.

A third classification of irregular galaxies are the dwarf irregulars, labeled as dI or dIrrs. This type of galaxy is now thought to be important to understand the overall evolution of galaxies, as they tend to have a low level of metallicity and relatively high levels of gas, and are thought to be similar to the earliest galaxies that populated the Universe. They may represent a local (and therefore more recent) version of the faint blue galaxies known to exist in deep field galaxy surveys.

Some irregular galaxies are small spiral galaxies that are being distorted by the gravity of a larger neighbor.

The Magellanic Cloud galaxies were once classified as irregular galaxies, but have since been found to contain barred spiral structures, and have been since re-classified as "SBm", a fourth type of barred spiral galaxy.

Peculiar Galaxy

A peculiar galaxy is a galaxy which is unusual in its size, shape, or composition. Peculiar galaxies come about as a result of interactions between galaxies, and they may contain atypical amounts of dust or gas, may have higher or lower surface brightness than a typical galaxy, or may have features such as nuclear jets. They can be highly irregular in shape due to the immense gravitational forces which act on them during encounters with other galaxies. Peculiar galaxies are designated by "p" or "pec" in catalogs such as the Halton Arp catalog.

Ring Galaxy

A ring galaxy is a galaxy with a ring-like appearance. The ring consists of massive, relatively young blue stars, which are extremely bright. The central region contains relatively little luminous matter. Astronomers believe that ring galaxies are formed when a smaller galaxy passes through the center of a larger galaxy. Because most of a galaxy consists of empty space, this "collision" rarely results in any actual collisions between stars. However the gravitational disruptions caused by such an event could cause a wave of star formation to move through the larger galaxy.

Polar-ring Galaxy

A polar-ring galaxy is a relatively rare type of galaxy, with only around 100 examples known. The best know example is NGC 4650A. It is theorized that the structure of these galaxies result from the collision of two galaxies. The collision results in a structure composed of two rings of material rotating at an approximate right angle to each other.

Dwarf Galaxy

A dwarf galaxy is any other type of galaxy that is of a smaller size; containing only a few million stars rather than hundreds of millions like their larger cousins. Some ultra-compact dwarf galaxies have been discovered that only measure 100 parsecs in diameter. Many dwarf galaxies orbit around a larger galaxy not unlike planets around a star.

<u>Unusual Dynamics and Activities</u>

Some galaxies have unusual properties or behaviors attributed to them.

Interacting

The average separation between galaxies within a cluster is a little over an order of magnitude larger than their diameter. Hence interactions between these galaxies are relatively frequent, and play an important role in their evolution. Near misses between galaxies result in warping distortions due to tidal interactions, and may cause some exchange of gas and dust.

[left] The Antennae Galaxies are undergoing a collision that will result in their eventual merger (NASA/ESA Hubble Space Telescope image)

Collisions occur when two galaxies pass directly through each other and have sufficient relative momentum not to merge. The stars within these interacting galaxies will typically pass straight through without colliding. However the gas and dust within the two forms will interact. This can trigger bursts of star formation as the interstellar medium becomes disrupted and compressed. A collision can severely distort the shape of one or both galaxies, forming bars, rings or tail-like structures.

At the extreme of interactions are galactic mergers. In this case the relative momentum of the two galaxies is insufficient to allow the galaxies to pass through each other. Instead they gradually merge together to form a single, larger galaxy. Mergers can result in significant changes to morphology, as compared to the original galaxies. In the case where one of the galaxies is much more massive, however, the result is known as cannibalism. In this case the larger galaxy will remain relatively undisturbed by the merger, while the smaller galaxy is torn apart. The Milky Way galaxy is currently in the process of cannibalizing the Sagittarius Dwarf Elliptical Galaxy and the Canis Major Dwarf Galaxy.

Starburst

Stars are created within galaxies from a reserve of cold gas that forms into giant molecular clouds. Some galaxies have been observed to form stars at an exceptional rate, known as a starburst. Should they continue to do so, however, they would consume their reserve of gas in a time frame lower than the lifespan of the galaxy. Hence starburst activity usually lasts for only about ten million years; a relatively brief period in the history of a galaxy. Starburst galaxies were more common during the early history of the universe, and, at present, still contribute an estimated 15% to the total star production rate.

Starburst galaxies are characterized by dusty concentrations of gas and the appearance of newly-formed stars, including massive stars that ionize the surrounding clouds to create H II regions. These massive stars also produce supernova explosions, resulting in expanding remnants that interact powerfully with the surrounding gas. These outbursts trigger a chain reaction of star building that spreads throughout the gaseous region. Only when the available gas is nearly consumed or dispersed does the starburst activity come to an end.

Starbursts are often associated with merging or interacting galaxies. The prototype example of such a starburst-forming interaction is M82, which experienced a close encounter with the larger M81 [picture right]. Irregular galaxies often exhibit spaced knots of starburst activity

Active Nucleus

A portion of the galaxies we can observe are classified as active. That is, a significant portion of the total energy output from the galaxy is emitted by a source other than the stars, dust and interstellar medium.

The standard model for an active galactic nucleus is based upon an accretion disk that forms around supermassive black hole (SMBH) at the core region. The radiation from an active galactic nucleus results from the gravitational energy of matter as it falls toward the black hole from the disk. In about 10% of these objects, a diametrically opposed pair of energetic jets ejects particles from the core at velocities close to the speed of light. The mechanism for producing these jets is still not well-understood.

[left]A jet of particles is being emitted from the core of the elliptical radio galaxy M87 (NASA/ESA Hubble Space Telescope image)

Active galaxies that emit high-energy radiation in the form of x-rays are classified as Seyfert galaxies or quasars, depending on the luminosity. Blazars are believed to be an active galaxy with a relativistic jet that is pointed in the direction of the Earth. A radio galaxy emits radio frequencies from relativistic jets. A unified model of these types of active galaxies explains their differences based on the viewing angle of the observer.

Possibly related to active galactic nuclei (as well as starburst regions) are low-ionization nuclear-emission regions, or LINERs. The emission from LINER-type galaxies is dominated by weakly-ionized elements. Approximately one-third of nearby galaxies are classified as containing LINER nuclei

Building a Sol-like System

Ok it's time to make a star system for colonization, or possibly for a near-human race to evolve. This guide follows the assumption of the "rare earth theory".

The Rare Earth hypothesis argues that the emergence of complex life required a host of fortuitous circumstances. A number of such circumstances are set out below under the following headings: galactic habitable zone, a central star and planetary system having the requisite character, the circumstellar habitable zone, the size of the planet, the advantage of a large satellite, conditions needed to assure the planet has a magnetosphere and plate tectonics, the chemistry of the lithosphere, atmosphere, and oceans, the role of "evolutionary pumps" such as massive glaciation and rare bolide impacts, and whatever led to the still mysterious Cambrian explosion of animal phyla. The emergence of intelligent life may have required yet other rare events.

In order for a small rocky planet to support complex life, the values of hundreds of variables must fall within narrow ranges. The universe is so vast that it could contain multiple Earth-like planets throughout millions of galaxies. But if such planets exist, they are likely to be separated from each other by many thousands of light years.

The galactic habitable zone

Rare Earth suggests that much of the known universe, including large parts of our galaxy, cannot support complex life; Ward and Brownlee refer to such regions as "dead zones." Those parts of a galaxy where complex life is possible make up the galactic habitable zone. This zone is primarily a function of distance from the galactic center. As that distance increases:

1) The metal content of stars declines, and metals are considered necessary to the formation of terrestrial planets.

2) The X-ray and gamma ray radiation from the supermassive black hole at the galactic center, and from nearby neutron stars and quasars, becomes less intense. Radiation of this nature is considered dangerous to complex life. Hence the Rare Earth hypothesis deems unfit for life the early universe, and regions where the stellar density is high and supernovae not rare.

3) Gravitational perturbation of planets and planetesimals by nearby stars becomes less likely as the density of stars decreases. Hence the further a planet lies from the galactic center, the less likely it is to be struck by a large bolide. A sufficiently large impact may extinguish all complex life on a planet.

Point (1) rules out the outer reaches of a galaxy; (2) and (3) rule out galactic inner regions, globular clusters, and the spiral arms of spiral galaxies. These arms are not physical objects, but regions of a galaxy characterized by a higher rate of star formation, moving very slowly through the galaxy in a wave-like manner. As one moves from the center of a galaxy to its furthest extremity, the ability to support life rises then falls. Hence the galactic habitable zone may be ring-shaped, sandwiched between its uninhabitable center and outer reaches.

While a planetary system may enjoy a location favorable to complex life, it must also maintain that location for a span of time sufficiently long for complex life to evolve. Hence a central star with a galactic orbit that steers clear of galactic regions where radiation levels are high, such as the galactic center and the spiral arms, would appear most favorable. If the central star's galactic orbit is eccentric (egg-shaped), it will pass through some spiral arms, but if the orbit is a near perfect circle and the orbital velocity equals the "rotational" velocity of the spiral arms, the star will drift into a spiral arm region only gradually, if at all. Therefore Rare Earth proponents conclude that a life-bearing star must have a galactic orbit that is nearly circular about the center of its galaxy. The required synchronization of the orbital velocity of a central star with the wave velocity of the spiral arms can occur only within a fairly narrow range of distances from the galactic center. This region is termed the "galactic habitable zone". Lineweaver et al (2004) calculate that the galactic habitable zone is an annular ring 7 to 9 kiloparsecs in diameter, that includes no more than 10% of the stars in the Milky Way. Based on conservative estimates of the total number of stars in the galaxy, this could represent something like 20 to 40 billion stars. Gonzalez (2001) would halve these numbers; he estimates that at most 5% of stars in the Milky Way fall in the galactic habitable zone.

The orbit of the Sun around the center of the Milky Way is indeed almost perfectly circular, with a period of 226 Ma, one closely matching the rotational period of the galaxy. However, Masters (2002) calculates that the orbit of the Sun takes it through a spiral arm approximately every 100 million years. In contrast, the Rare Earth hypothesis predicts that the Sun, since its formation, should have passed through no spiral arm at all.

The Star Itself

It is generally accepted by exobiologists that the central star for a life-bearing planet must be of appropriate size. Large stars emit much ultraviolet radiation, which precludes life other than underground microbes. Large stars also exist for millions, not billions, of years, after which they explode as supernovae. A supernova remnant becomes a neutron star or black hole, giving off high energy x-ray and gamma radiation. Hence the planets orbiting the large hot or binary stars believed to give rise to supernovae do not live long enough to allow their planets to evolve complex life.

The terrestrial example suggests complex life requires water in the liquid state and its planet must therefore be at an appropriate distance. This is the core of the notion of habitable zone. The habitable zone forms a ring around the central star. If a planet orbits its sun too closely or too far away, the surface temperature is incompatible with water being liquid (though sub-surface water, as suggested for Europa, may be possible at varying locations). Kasting et al (1993) estimate that the habitable zone for the Sun ranges from 0.95 to 1.15 astronomical units.

The habitable zone varies with the type and age of the central star. The habitable zone for a main sequence star very gradually moves out over time until the star becomes a white dwarf, at which time the habitable zone vanishes. The habitable zone is closely connected to the greenhouse warming afforded by atmospheric carbon dioxide (CO_2). Even though the Earth's atmosphere contains only 350 parts per million of CO_2, that trace amount suffices to raise the average surface temperature of the Earth by about 40°C from what it would otherwise be (Ward and Brownlee 2000: 18).

It is then presumed a star needs to have rocky planets within its habitable zone. While the habitable zone of hot stars, such as Sirius or Vega is wide, there are two problems:

1) Given that rocky planets tend to form closer to their central stars, the minimum radius of the habitable zone may be greater than the orbital radius of any rocky planet. This does not rule out life on a moon of a gas giant. Hot stars also emit much more ultraviolet radiation, which will ionize any planetary atmosphere.

2) Hot stars as mentioned above, have short lives, becoming red giants in as little as 1 Ga. This may not allow enough time for advanced life to evolve.

These considerations rule out the massive and powerful stars of type F6 to O (see stellar classification).

Small red dwarf stars, on the other hand, have habitable zones with a small radius. This proximity causes one face of the planet to constantly face the star, and the other to always remain dark, a situation known as tidal lock. Tidal lock rules out axial rotation; hence one side of a planet will be extremely hot, while the other will be extremely cold. Planets within a habitable zone with a small radius are also at increased risk of solar flares (see Aurelia), which would tend to ionize the atmosphere and are otherwise inimical to complex life. Rare Earth proponents argue that this rules out the possibility of life in such systems, though some exobiologists have suggested that habitability may exist under the right circumstances. This is a central point of contention for the theory, since these K and M category stars are estimated to make up 90% of all stars.

Rare Earth proponents argue that the stellar type of central stars that are "just right" ranges from F7 to K1. Such stars are not common: G type stars such as the Sun (between the hotter F and cooler K) comprise only 5% of the stars in the Milky Way. Aged stars, such as red giants, and white dwarfs, are also unlikely to support life. Red giants are common in globular clusters and elliptical galaxies. White dwarfs are mostly dying stars that have already gone through their red giant phase. The diameter of a red giant has substantially increased from its youth. If a planet was in the habitable zone during a star's youth and middle age, it will be fried when its parent star becomes a red giant (though theoretically planets at a much greater distance may become habitable).

The energy output of a star over its lifespan should only change very gradually; variable stars such as a Cepheid variables, for instance, are highly unlikely to support life. If the central star's energy output suddenly decreases, even for a relatively short while, the planet's water may freeze. Conversely, if the central star's energy output temporarily increases, the oceans may evaporate, resulting in a greenhouse effect; this may preclude the oceans from reforming.

There is no known way to achieve life without complex chemistry, and such chemistry requires metals, namely elements other than hydrogen, helium, and lithium. This suggests a condition for life is a solar system rich in metals. The only known mechanism for creating and dispersing metals is a supernova explosion. The presence of metals in stars is revealed by their absorption spectrum, and studies of stellar spectra reveal that many, perhaps most, stars are poor in metals. Low metallicity characterizes the early universe, globular clusters and other stars formed when the universe was young, stars in most galaxies other than large spirals, and stars in the outer regions of all galaxies. Thus metal-rich central stars capable of supporting complex life are believed most common in the quiet suburbs of the larger spiral galaxies, regions hospitable to complex life for another reason, namely the absence of high radiation.

If a star is poor in metals, any associated planetary system is likely poor in metals as well. In order to have rocky planets like the Earth, a central star must have condensed out of a nebula that was fairly metal-rich. Only gas giant planets will condense out of a metal-poor nebula; such a nebula simply lacks the material required to form terrestrial planets.

Planetary System

A gas cloud capable of giving birth to a star can also give rise to gas giant (Jovian) planets like Jupiter and Saturn. But Jovian planets have no hard surface of the kind believed necessary for complex life (their satellites may have hard surfaces, though). Hence a planetary system capable of sustaining complex life must be structured more or less like the solar system, with small and rocky inner planets, and Jovian outer ones.

Thanks to its gravitational force, a gas giant ejects the debris from planet formation into the equivalent of the Kuiper belt and Oort cloud. Hence a gas giant helps protect the inner rocky planets from asteroid bombardment. However, a gas giant must not be too close to a body upon which life is developing, unless that body is one of its moons. A gas giant must also not be too close to another gas giant. Either placement of the gas giant(s) could disrupt the orbit of a potential life-bearing planet, either directly or by drifting into the habitable zone. Furthermore, some (if not many) gas giants produce a tremendously strong magnetic/radiation belt that envelops its moons.

Newtonian dynamics predict that all planetary orbits will tend to be chaotic. This tendency to chaos is much stronger when orbits are eccentric, especially the orbits of large planets. The need for stable orbits rules out planetary systems resembling those that have been discovered in recent years, namely systems with a large planet with a small orbit. Such planets are known as hot Jupiters. It is believed that hot Jupiters formed much further from their parent stars than they are now, and have gradually migrated inwards to their current orbits. In the process, they would have gravely disrupted the orbits of any inner planets in the habitable zone.

Planetary systems, especially their outer regions, are believed to be riddled with comets and asteroids which inevitably collide with planets. Such collisions, known as bolide impacts, can be highly disruptive for complex life. Hence bolide impacts must be rare (but nonexistent is not necessarily for the best either; see below) during the billions of years required for complex life to emerge. The frequency of bolide impacts on inner planets is reduced if there are lifeless planets at the right distance from the central star, and with sufficient gravity either to attract comets and asteroids to themselves or to eject them from the planetary system.

Hence a planetary system capable of supporting complex life must include at least one large outer planet. Jupiter's large mass has attracted many (nearly all?) of the bolides that would have otherwise hit Earth since the end of the late heavy bombardment about 3.8 Ga. But planetary systems with too many Jovian planets, or with a single one that is too large, are likely to be unstable, in which case the likely fate of a rocky inner planet able to support life is either to plunge into its central star or to be ejected into interstellar space.

Size of planet

(Lissauer 1999, as summarized by Conway Morris 2003: 92; also see Comins 1993). A planet that is too small cannot hold much of an atmosphere. Hence the surface temperature becomes more variable and the average temperature drops. Water will either freeze, boil away, or decompose under the action of UV radiation; in any event, substantial and long-lasting oceans become impossible. A small planet will also tend to have a rough surface, with large mountains and deep canyons. The core will cool faster, and plate tectonics will either not last as long as they would on a larger planet or may not occur at all.

If a planet's size is such that its gravitational field substantially exceeds the Earth's, it will attract more bolides to itself. The stronger the gravitational field, the harder it is for mountains and continents to form. In the limit, such a planet would probably be covered with an ocean, in which case the lack of exposed rocks would rule out the feedback mechanism, described below, regulating atmospheric CO2.

Large moon

The Moon is unusual because:

1) The other rocky planets in the Solar System either have no satellites (Mercury and Venus), or have tiny satellites that are likely to be captured asteroids (Mars).

2) As a fraction of its planet, it is much larger than any other satellite in the Solar System except Pluto's Charon. It is also atypically close.

The giant impact theory hypothesizes that the Moon results from the impact of a Mars-sized body (referred to as Theia) with the very young Earth. This giant impact also gave the Earth its axis tilt and velocity of rotation (Taylor 1998). Rapid rotation reduces the daily variation in temperature and makes photosynthesis viable. The Rare Earth hypothesis further argues that the axis tilt cannot be too large or too small (relative to the orbital plane). A planet with a large tilt will experience extreme seasonal variations in climate, unfriendly to complex life. A planet with little or no tilt will lack the stimulus to evolution that climate variation provides. In this view, the Earth's tilt is "just right". A large satellite can also act as a gyroscope, stabilizing the planet's tilt; without this effect the tilt will be chaotic, presumably also causing difficulties for developing life forms.

If the Earth had no Moon, the ocean tides resulting solely from the Sun's gravity would be very modest. A large satellite gives rise to substantial tides and the resulting tidal pools, which are likely to have been an important focus for the evolution of complex life. A large satellite also increases the likelihood of plate tectonics through the effect of tidal forces on the planet's crust. The impact that formed the Moon may also have initiated plate tectonics, without which the continental crust would cover the entire planet, leaving no room for oceanic crust. It is possible that the large scale mantle convection needed to drive plate tectonics could not have emerged in the absence of crustal inhomogeneity.

If a giant impact is the only known way for a rocky inner planet to acquire a large satellite, any planet in the circumstellar habitable zone will need to form as a double planet in order that there be an impacting object sufficiently massive to give rise in due course to a large satellite. An impacting object of this nature is not necessarily improbable. Recent work by Edward Belbruno and J. Richard Gott of Princeton University suggests that a suitable impacting body could form in a planet's trojan points (L4 or L5).

Magnetic field

A magnetosphere protects the biosphere from solar wind and cosmic rays, which are harmful to life. The magnetosphere results from a massive conductive planetary core made of molten iron, acting as a dynamo. The iron is molten because of heat given off by the decay of radioactive elements. If complex life can exist only on the surface of a planet surrounded by a magnetosphere, then complex life requires a planet whose interior contains radioactive elements. Moreover, these elements must have half lives long enough (e.g., uranium 238, thorium 232, and potassium 40) to sustain the magnetosphere for a time span long enough for complex life to evolve. Such elements are relatively rare in the universe. As the universe grows older, the frequency of the sort of supernovae that produces radioactive elements with long half lives is believed to decline. Hence these elements are fated to grow ever rarer as the universe grows older. Hence there is possibly an upper bound to the age of a universe capable of supporting complex life.

The unusually massive iron core that generates the Earth's magnetosphere may have resulted from the merger of the proto-Earth's smaller core with that of an impacting body. This impacting body could have been the one that, under the giant impact theory (see above), gave rise to the Moon.

Plate tectonics

This is the most original part of Ward and Brownlee's analysis (however this section owes much to Webb 2002: 180-84). They argue that in order for a rocky planet to support animal life, its crust must experience plate tectonics. That is, the lithosphere must consist of large crustal plates that, along certain margins, are continuously created from fluid matter carried from the deep interior in convection cells. Along other margins, called subduction zones, these crustal plates are reabsorbed into the planet's interior.

A planet will not experience plate tectonics unless its chemical composition allows it. The only known long lasting source of the required heat is radioactive decay occurring deep in the planet's interior. Continents must also be made up of less dense granitic rocks that "float" on underlying more dense basaltic rock. Taylor (1998) emphasizes that subduction zones (an essential part of plate tectonics) require the lubricating action of ample water; on Earth, such zones exist only at the bottom of oceans.

A large satellite also increases the likelihood of plate tectonics through the effect of tidal forces on the planet's crust. The impact that formed the Moon may also have initiated plate tectonics, without which the continental crust would cover the entire planet, leaving no room for oceanic crust. At present, it is not known whether the organization of the large scale mantle convection needed to drive plate tectonics could develop in the absence of crustal inhomogeneity.

The reasons why convection-driven plate tectonics promotes the development of complex life include the following. Plate tectonics:

1) Enable the magnetosphere;
2) Create and alter dry land via magmatic differentiation;
3) Regulate the temperature of the atmosphere.

By drawing heat from the interior to the surface, convection driven plate tectonics assures that if a planet has a core of molten iron, that core keeps moving. That motion means that the core of the earth acts like a dynamo, generating a magnetic field.

If the atmosphere contains too few greenhouse gases, the planet slides into a permanent ice age. Too much greenhouse gas, and the temperature becomes first too high for complex life (many proteins denature at temperatures well short of the boiling point of water), and eventually the oceans turn to water vapor. The primary greenhouse gas in the Earth's atmosphere is carbon dioxide, CO_2. It appears that plate tectonics play an important role in a complex feedback system (for details, see Ward and Brownlee) that stabilizes the Earth's temperature. Atmospheric CO_2 combines with rainwater to form dilute carbonic acid. This acid interacts with surface rocks to form calcium carbonate, $CaCO_3$, which is eventually deposited on the ocean bottom and carried into the Earth's interior at subduction zones. Thus CO_2 is removed from the atmosphere. The high temperatures and pressures within the Earth's mantle transform $CaCO_3$ into CO_2 and CaO. This subterranean CO_2 is eventually returned to the atmosphere via volcanism.

Feedback occurs because a rise in atmospheric CO_2 results in higher temperatures via the greenhouse effect, and more rainfall, and more acid rainwater. Hence the rate at which CO_2 is removed from the atmosphere rises. When atmospheric CO_2 falls, the rate at which it is removed from the atmosphere declines. Plate tectonics exposes and buries rocks in a way that automatically regulates the CO_2 content of the atmosphere. The result has been an Earth with a more or less steady surface temperature, even though the sun's energy output is believed to be about 25% greater now than it was when the Earth was

young. Absent this recycling of atmospheric carbon, the expected lifetime of the biosphere is not expected to exceed a few million years. Ice ages, by covering much of a planet's rocks and by reducing rainfall, interfere with this feedback process.

It is difficult to imagine how an aquatic species would smelt and shape metal ores or manipulate electricity (sea water is a fair electrical conductor thanks to its dissolved minerals). Hence it is likely that intelligent life with technology can only evolve on dry land; plate tectonics assures that a planet with ample water also has dry land. More generally, a planet with mountains, islands, and continents gives rise to more microclimates and evolutionary niches, which present evolution with more challenges. Hence plate tectonics promote biodiversity.

While plate tectonics appear to have helped complex life to evolve on Earth, how essential plate tectonics are for complex life in general, and the rarity of planets with plate tectonics, are both not well understood at present. The only object in the solar system other than the Earth believed to experience plate tectonics now is the Galilean moon Europa.

The atmosphere

Carbon-based biochemistry clearly requires a large supply of atmospheric carbon dioxide and crustal carbon (in the form of carbonate compounds); however large amounts of carbon would give rise to a runaway greenhouse effect. Atmospheric oxygen is necessary to support the metabolism of Earthly animals and hence intelligent life. Hence something like photosynthesis had to evolve to shift the atmosphere from a reducing one to an oxidizing one.

Central stars invariably emit ultraviolet (UV) radiation. UV radiation whose wavelength falls in the range of 260-90 nm is efficiently absorbed by nucleic acids and proteins, and hence is lethal for all forms of terrestrial life. Fortunately, ozone efficiently absorbs UV radiation in the range 200-300 nm, and atmospheric oxygen is the building block for ozone. Hence a planet with complex life living on dry land must have an ozone layer in its upper atmosphere. Oxygen first appeared in the atmosphere when UV radiation in the range 100-200 nm broke water down into its atomic components. Once there was enough of an ozone layer to permit photosynthetic microbes to evolve on the planet's surface, the oxygen content of the atmosphere gradually rose through photosynthesis, and is believed to have reached its present (or even higher) level during the Cambrian era. Hence an atmosphere sufficiently rich in oxygen may have been a necessary condition for the Cambrian explosion.

Even if conditions on a planet's surface allow water in the liquid phase, we cannot conclude that there will in fact be any water present. The inner planets in our solar system were formed with little water. Much of the water in the oceans is believed to have been brought to Earth by the icy asteroid impacts during the early bombardment phase about 4.5 Ga. The oceans play a crucial role in moderating the seasonal swings in the Earth's temperature. The high specific heat of water enables oceans to warm slowly during the summer and then to give up their summer heat over the following winter. Too much water, on the other hand, leads to a planet with little or no land, and hence no weathering mechanism for regulating the carbon dioxide content of the atmosphere.

Evolutionary "pumps"

Even if all of these above conditions are met, complex life does not necessarily evolve. There is no evidence whatsoever of life until 3.8 Ga, when the late heavy bombardment ended, marking the end of the Hadean eon. Over the next 3.2 Ga, there is no evidence, other than a few possible worm tracks, of life more complex than the protists; if there were proto-nematodes or other small soft bodied organisms, they left no fossils.

The terrestrial fossil record is thought to show that a complex ecosystem, consisting of many niches, each filled, has been attained several times, the first being just after the Cambrian Explosion. The theory of Punctuated equilibrium argues that:

1) Once a planet has an ecosystem whose niches are all filled, the rate of evolutionary change drops considerably;

2) On Earth, the time required for evolution to fill all niches (to reach equilibrium) has been relatively short compared to geological time.

An "evolutionary pump" is any mass extinction event that results in many empty ecological niches, thereby speeding up evolution. Such events, which can place all of a planet's complex life at risk, include a sudden change in the energy put out by the central star, a collapse of the magnetosphere, a sudden change in a planet's spin rate or axial tilt, a nearby supernova, gamma ray bursts anywhere in the galaxy (perhaps resulting from merging neutron stars), and any rapid and drastic change in climate or ocean chemistry. Rare Earth focuses on two candidate evolutionary pumps, global glaciation, and bolide impacts.

Global glaciation

The evolution of life on Earth includes two very important and unexpected leaps, the emergence of:

1) Unicellular eukaryotes characterized by organelles, such as chromosomes, nuclei, and mitochondria;

2) Multicellular life with specialized biological tissues and organs, especially animals with calcified shells and skeletons, capable of leaving a clear fossil record.

The earliest unambiguous fossil evidence of multicellular life is the Ediacaran biota, about 580 Ma. Hence the better part of 2 billion years elapsed between the first and the second leaps. Meanwhile, only about 400 million years were required in order for the first multicellular animals (sponges and Ediacaran biota) to evolve into dinosaurs.

Curiously, both of these evolutionary transitions came hard on the heels of extended periods of glaciation so extensive that it is suspected that the earth was covered with ice, either entirely or over all but a narrow band about the Equator. This much ice cover would have raised the Earth's albedo to such an extent that the Earth's average temperature may have fallen to about -50°C. The thick ice covering almost all oceans ruled out any interactions between the oceans and the atmosphere. The continents were either covered with ice, or consisted of bare rock devoid of life. This scenario has been named Snowball Earth.

During such periods of catastrophic glaciation, life probably retreated to a narrow band near the equator, and to places warmed by tectonic activity, such as hydrothermal vents on the ocean floor, and volcanoes. Fortunately, glaciation interferes neither with plate tectonics nor with the resulting vulcanism. A hypothesized eventual rise in

vulcanism increased atmospheric levels of greenhouse gases, which led to a dramatic increase in temperature and the end of the two apparent snowball earth episodes.

The first Snowball Earth episode, the Huronian glaciation, began about 2.4 Ga, shortly after the appearance of the oldest known eukaryotic unicellular organisms. The second episode, the Cryogenian period, lasted from 850 Ma to 635 Ma, ending about 50 Ma before the emergence of the Ediacaran biota. It is an open question what role, if any, these ice ages played in triggering the emergence of complex life. In any event, when the glaciation ended, life eventually sprang back with renewed vigor and diversity. The Cambrian explosion began 542 Ma, in which representatives of all currently extant (and some now extinct) animal phyla suddenly appear in the fossil record. Just how or why the Cambrian explosion came about is still not understood, but it is likely to have resulted from one or more "evolutionary pumps."

More modest glaciations are also associated with rapid evolutionary change. The rapid evolution of hominids, which culminated in the appearance of homo sapiens about 200 ka, coincides with the oscillating Quarternary ice age that began about 1.5 Ma. Moreover, the agricultural revolution, when homo sapiens emerged as an aggressive discover of technology, began shortly after the last glacial retreat, around 12 Ka.

Bolide impacts

The impact of a sufficiently massive asteroid or comet can act as an evolutionary pump. The evolution of complex life requires long periods of tranquility. Frequent impacts from large bolides, while not incompatible with the emergence and survival of microbes, make it unlikely that complex life will emerge and survive. Rare bolide impacts, however, while making many forms of complex life extinct, on balance appear to act as evolutionary pumps. A small number of mass-extinction events may be required to give evolution the chance to explore radical new approaches to the challenges of the environment, rather than remain trapped in a suboptimal local maximum. By "suboptimal" is meant "the likelihood that human-like intelligence will eventually emerge is not at a maximum."

A case in point is the asteroid impact that created the Chicxulub Crater, believed to have triggered the Cretaceous-Tertiary extinction event, when an estimated 70% of extant metazoans species, including all dinosaurs, became extinct. By removing dinosaurs from all niches they happened to fill, the K-T extinction opened the way for mammals to become large and take their place.

Inertial interchange event

There is ample evidence that the rate of continental drift during the Cambrian explosion was unusually high. In fact, continents moved from Arctic to equatorial locations, and vice versa, in 15 million years or less. Kirschvink et al (1997) have proposed the following controversial explanation: a 90° change in the Earth's axis of rotation resulting from an imbalance in the distribution of continental masses relative to the axis. The result was huge changes in climates, ocean currents, and so on, occurring in a very short time and affecting the entire Earth. They named their explanation the "inertial interchange event." This scenario is not yet received science, but if such an event took place and is a very unlikely occurrence, and if such an event was required for the

evolution of animal life more complex than sponges and coral reefs, then we have yet another reason why complex life will be rare in the universe.

Considerations

The Rare Earth hypothesis only assumes the formation of complex life (multicellular life). This does not cover the possibility of *intelligent* life forming nor that intelligent life discovering and developing technology. According to this hypothesis, the earth might be the *only* planet in the galaxy to have complex life at all; and if there are others, they are so far away that any attempt at communication is futile at best.

Further details on the distribution of life throughout the galaxy and Drake's Theory are covered in Chapter 14: Aliens.

The Galaxy of Macross

The Macross series can be easily explained with the Rare Earth hypothesis in the fact that the first and only intelligent life to evolve in this galaxy was the Protoculture themselves. Humans, Zentraedi and Zolans all were created, altered or seeded on planets by the Protoculture and thus do not fall into the Rare Earth hypothesis cleanly. It is not impossible that other complex or intelligent life *did* in fact form, however the lack of any signs of them in the Macross saga would suggest they are on the opposite side of the galaxy or were rendered extinct by the Protodeviln or the Schism War.

One of the major themes of Macross is searching out hospitable planets to colonize and thus ensure the survival of the human (and Zentraedi) race. Such hospitable planets would still have to meet most of the requirements for the evolution of complex life since there would be need of plant and animal life.

In the galaxy of Macross, terraforming available with the technology in the 2030's. If a planet is close to earth-like but needs minor alterations, it can be done. However, terraforming may well have been commonplace by the Protoculture, given their other fantastic technologies.

Varauta

The 3rd planet, Raxx, was a near-earth planet with large oceans and continents. Little detail was given on the world other than it was once a science colony of the Protoculture and was thus likely a near-earth planet even at that time. It is assumed the planet had similar seasons, weather patterns and day/night cycles as earth.

The 4th planet was a frozen ball of ice with high winds and constant snowstorms. Because several pilots were shown surviving on the surface for a short time, the atmosphere is close to that of earth, and the snow and ice are likely water rather than toxic elements such as methane or ammonia.

Zola

Zola is shown with a ring of large rocky debris. It is quite likely that the planet at one point possessed a moon comparable to the one orbiting the earth, but that moon was shattered by either collision with large asteroid or planetoid or from the Schism War; or possibly from massed firepower.

Vajra Homeworld

This unnamed planet has three small moons and an artificial ring around the equator. It is presumed this artificial ring was constructed by the Protoculture, as it was once one of their worlds (if not their homeworld).

Stars

The first part of a star system is of course the star itself. A star is a massive ball of luminous plasma generating various types of radiation including light and heat through a process of internal nuclear fusion.

Astronomers can determine the mass, age, chemical composition and many other properties of a star by observing its spectrum, luminosity and motion through space. The total mass of a star is the principal determinant in its evolution and eventual fate. Other characteristics of a star that are determined by its evolutionary history include the diameter, rotation, movement and temperature. A plot of the temperature of many stars against their luminosities, known as a Hertzsprung-Russell diagram (H-R diagram), allows the current age and evolutionary state of a particular star to be determined.

A star begins as a collapsing cloud of material that is composed primarily of hydrogen along with some helium and heavier trace elements. Once the stellar core is sufficiently dense, some of the hydrogen is steadily converted into helium through the process of nuclear fusion. The remainder of the star's interior carries energy away from the core through a combination of radiation and convective processes. These processes keep the star from collapsing upon itself and the energy generates a stellar wind at the surface and radiation into outer space.

Binary and multi-star systems consist of two or more stars that are gravitationally bound, and generally move around each other in stable orbits. When two such stars have a relatively close orbit, their gravitational interaction can have a significant impact on their evolution.

Measuring a Star

Most stellar parameters are expressed in SI units by convention, but CGS units are also used (e.g., expressing luminosity in ergs per second). Mass, luminosity, and radii are usually given in solar units, based on the characteristics of the Sun:

solar mass: $M_\odot = 1.9891 \times 10^{30}$ kg

solar luminosity: $L_\odot = 3.827 \times 10^{26}$ watts

solar radius: $R_\odot = 6.960 \times 10^{8}$ m

Large lengths, such as the radius of a giant star or the semi-major axis of a binary star system, are often expressed in terms of the astronomical unit (AU) — approximately the mean distance between the Earth and the Sun (150 million km or 93 million miles).

Star Formation

Star formation is the process by which dense parts of molecular clouds collapse into a ball of plasma to form a star. As a branch of astrophysics Star Formation includes the study of the interstellar medium and giant molecular clouds as precursors to the star formation process and the study of early type stars and planet formation as its immediate

products. Star formation theory, as well as accounting the formation of a single star, must also account for the statistics of binary stars and the initial mass function.

According to current theories of star formation, cores of molecular clouds (regions of especially high density) become gravitationally unstable, fragment, and begin to collapse (the so-called *spontaneous star formation*) or shockwaves from supernovae or other energetic astronomical processes trigger star formation in nearby nebulae (the so-called *triggered star formation*). Part of the gravitational energy lost in this collapse is radiated in the infrared, with the remainder increasing the temperature of the core of the object. The accretion of material happens partially through a circumstellar disc. When the density and temperature are high enough, deuterium fusion ignition occurs, and the outward pressure of the resultant radiation slows (but does not stop) the collapse. Material comprising the cloud continues to "rain" onto the protostar. In this stage bipolar flows are produced, probably an effect of the angular momentum of the infalling material. Finally, hydrogen begins to fuse in the core of the star, and the rest of the enveloping material is cleared away.

The protostar follows a Hayashi track on the Hertzsprung-Russell diagram. The contraction will proceed until the Hayashi boundary is reached, and thereafter contraction will continue on a Kelvin-Helmholtz timescale with the temperature remaining stable. Stars with less than 0.5 solar masses thereafter join the main sequence. For more massive protostars, at the end of the Hayashi track they will slowly collapse in near hydrostatic equilibrium, following the Henyey track.

The Hayashi track is a path taken by protostars in the Hertzsprung-Russell diagram after the protostellar cloud has reached approximate hydrostatic equilibrium. In 1961 Chushiro Hayashi showed that there is a minimum effective temperature (equivalently, a boundary on the right-hand side of the H-R diagram) cooler than which hydrostatic equilibrium cannot be maintained; this boundary corresponds to a temperature around 4000 K. Protostellar clouds cooler than this will contract and heat up until they reach the Hayashi boundary. Once at the boundary, a protostar will continue to contract on the Kelvin-Helmholtz timescale, but its effective temperature will no longer increase, as it will remain at the Hayashi boundary. Thus the Hayashi track is close to a vertical line on the H-R diagram. Stars at the Hayashi boundary are fully convective: this is because they are cool and highly opaque, so that radiative energy transport is not efficient, and consequently have large internal temperature gradients. Stars with masses <0.5 Solar mass remain on the Hayashi track (i.e. are fully convective) throughout their pre-main sequence stage, joining the main sequence at the bottom of the Hayashi track. For stars with masses > 0.5 Solar mass the Hayashi track ends, and the Henyey track begins, when the internal temperature of the star rises high enough that its central opacity drops and radiative energy transport becomes more efficient than convective transport: the lowest luminosity on the Hayashi track for a star of a given mass is thus the lowest luminosity at which it is still fully convective

The stages of the process are well defined in stars with masses around one solar mass or less. In high mass stars, the length of the star formation process is comparable to the other timescales of their evolution, much shorter, and the process is not so well defined. The later evolution of stars are studied in stellar evolution.

Observations

Key elements of star formation are only available by observing in wavelengths other than the optical. The structure of the molecular cloud and the effects of the protostar can be observed in near-IR extinction maps (where the number of stars are counted per unit area and compared to a nearby zero extinction area of sky), continuum dust emission and rotational transitions of CO and other molecules; these last two are observed in the millimeter and submillimeter range. The radiation from the protostar and early star has to be observed in infrared astronomy wavelengths, the extinction caused by the rest of the cloud where it is being formed is usually too big to allow us to observe it in the visual part of the spectrum. This presents considerable difficulties as the atmosphere is almost entirely opaque from 20um to 850um, with narrow windows at 200 and 450um. Even outside this range atmospheric subtraction techniques must be used.

The formation of individual stars can only be directly observed in our Galaxy, but in distant galaxies star formation has been detected through its unique spectral signature.

Low Mass vs. High Mass Star Formation

Stars of different masses are thought to form by slightly different mechanisms. The theory of low-mass star formation, which is well-supported by a plethora of observations, suggests that low-mass stars form by the gravitational collapse of rotating density enhancements within molecular clouds. As described above, the collapse of a rotating cloud of gas and dust leads to the formation of an accretion disk through which matter is channeled onto a central protostar. For stars with masses higher than about 8 solar masses, however, the mechanism of star formation is not well understood.

Massive stars emit copious quantities of radiation which pushes against infalling material. In the past, it was thought that this radiation pressure might be substantial enough to halt accretion onto the massive protostar and prevent the formation of stars with masses more than a few tens of solar masses. Recent theoretical work has shown that the production of a jet and outflow clears a cavity through which much of the radiation from a massive protostar can escape without hindering accretion through the disk and onto the protostar. Present thinking is that massive stars may therefore be able to form by a mechanism similar to that by which low mass stars form.

There is mounting evidence that at least some massive protostars are indeed surrounded by accretion disks. Several other theories of massive star formation remain to be tested observationally. Of these, perhaps the most prominent is the theory of competitive accretion, which suggests that massive protostars are "seeded" by low-mass protostars which compete with other protostars to draw in matter from the entire parent molecular cloud, instead of simply from a small local region. Another theory of massive star formation suggests that massive stars may form by the coalescence of two or more stars of lower mass.

Main Sequence

The main sequence of the Hertzsprung-Russell diagram is the curve along which the majority of stars are located. Stars on this band are known as main-sequence stars or dwarf stars.

This line is so pronounced because both the spectral type and the luminosity depend only on a star's mass (to 0^{th} order) as long as it is fusing hydrogen - and that is what almost all stars spend most of their "active" life doing.

At closer inspection, one notices that the main sequence does not look like a line and it isn't but instead somewhat fuzzy. There are many reasons for this fuzziness, the most important one still being observational uncertainties which mainly affect the distance of the star in question but range all the way to unresolved binary stars.

But even perfect observations would lead to a fuzzy main sequence, because mass is not a star's only parameter. Chemical composition and—related—its evolutionary status also move a star slightly on the main sequence, as do close companions, rotation, or magnetic fields, to name just a few. Actually, there are very metal-poor stars (subdwarfs) that lie just below the main sequence although they are fusing hydrogen, thus marking the lower edge of the main sequence's fuzziness due to chemical composition.

Astronomers will sometimes refer to the "zero age main sequence", or ZAMS. This is a line calculated by computer models of where a star will be when it begins hydrogen fusion; its brightness and surface temperature typically increase from this point with age. Stars usually enter and leave the main sequence from about when they are born or when they are starting to die, respectively.

Our Sun is a main-sequence star—it has been one for about 4.5 billion years and will continue to be one for another 4.5 billion years. It has the spectral classification of G2 V. After the hydrogen supply in the core is exhausted, it will expand to become a red giant.

The total main sequence lifetime of a star can be estimated from its mass relative to the Sun's as follows:

$$\tau_{ms} \sim 10^{10} \cdot \left[\frac{M_\odot}{M}\right]^{2.5} \text{ years}$$

where $M_\odot$ is the mass of the sun, M is the mass of the star and τms is the star's estimated main sequence lifetime in years. The lightest stars, of less than a tenth of solar mass, may last over a trillion years, whilst the heaviest last only a few tens of thousands of years.

The table below shows typical values for stars along the main sequence. The values of luminosity (L), radius (R), and mass (M) are relative to the Sun. The actual values for a star may vary by as much as 20-30%. The coloration of the stellar class column gives an approximate representation of the star's photographic color.

Class	Temperature	Star color	Mass	Radius	Luminosity	Hydrogen lines
O	30,000 – 60,000 K	Bluish ("blue")	60	15	1,400,000	Weak
B	10,000 – 30,000 K	Bluish-white ("blue-white")	18	7	20,000	Medium

A	7,500 – 10,000 K	White with bluish tinge ("white")	3.1	2.1	80	Strong
F	6,000 – 7,500 K	White ("yellow-white")	1.7	1.3	6	Medium
G	5,000 – 6,000 K	Light yellow ("yellow")	1.1	1.1	1.2	Weak
K	3,500 – 5,000 K	Light orange ("orange")	0.8	0.9	0.4	Very weak
M	2,000 – 3,500 K	Reddish orange ("red")	0.3	0.4	0.04	Very weak

Stellar Class	Radius	Mass	Luminosity	Temperature
	$R/R_\odot$	$M/M_\odot$	$L/L_\odot$	K
O2	16	158	2,000,000	54,000
O5	14	58	800,000	46,000
B0	5.7	16	16,000	29,000
B5	3.7	5.4	750	15,200
A0	2.3	2.6	63	9,600
A5	1.8	1.9	24	8,700
F0	1.5	1.6	9.0	7,200
F5	1.2	1.35	4.0	6,400
G0	1.05	1.08	1.45	6,000
G2	1.0	1.0	1.0	5,700
G5	0.98	0.95	0.70	5,500
K0	0.89	0.83	0.36	5,150
K5	0.75	0.62	0.18	4,450
M0	0.64	0.47	0.075	3,850

M5	0.36	0.25	0.013	3,200
M8	0.15	0.10	0.0008	2,500
M9.5	0.10	0.08	0.0001	1,900

"Oh Be A Fine Girl, Kiss Me" is a phrase used to aid memory of the sequence.

O Class

Class O stars are very hot and very luminous, being bluish in color; in fact, most of their output is in the ultraviolet range. These are the rarest of all main sequence stars, constituting as few as 1 in 32,000. O-stars shine with a power over a million times our Sun's output. These stars have prominent ionized and neutral helium lines and only weak hydrogen lines. Because they are so huge, Class O stars burn through their hydrogen fuel very quickly, and are the first stars to leave the main sequence. Recent observations by the Spitzer Space Telescope indicate that planetary formation does not occur within the vicinity of an O class star due to the Photo evaporation effect.

B Class

Class B stars are extremely luminous and blue. Their spectra have neutral helium and moderate hydrogen lines. As O and B stars are so powerful, they only live for a very short time, and thus they do not stray far from the area in which they were formed. These stars tend to cluster together in what are called OB1 associations, which are associated with giant molecular clouds. The Orion OB1 association occupies a large portion of a spiral arm of our Galaxy and contains many of the brighter stars of the constellation Orion. They constitute about 0.13% of main sequence stars -- rare, but much more common than those of class O.

A Class

Class A stars are amongst the more common naked eye stars. As with all class A stars, they are white or bluish-white. They have strong hydrogen lines and also lines of ionized metals. They comprise perhaps 0.63% of all main sequence stars.

F Class

Class F stars are still quite powerful but they tend to be main sequence stars. Their spectra is characterized by the weaker hydrogen lines and ionized metals, their color is white with a slight tinge of yellow. These represent 3.1% of all main sequence stars.

G Class

Class G stars are probably the best known, if only for the reason that our Sun is of this class. They have even weaker hydrogen lines than F, but along with the ionized metals, they have neutral metals. G is host to the "Yellow Evolutionary Void". Supergiant stars often swing between O or B (blue) and K or M (red). While they do this, they do not stay for long in the G classification as this is an extremely unstable place for a supergiant to be. These are about 8% of all main sequence stars.

K Class

Class K are orangish stars which are slightly cooler than our Sun. Some K stars are giants and supergiants, such as Arcturus while others like Alpha Centauri B are main sequence stars. They have extremely weak hydrogen lines, if they are present at all, and mostly neutral metals. These make up some 13% of main sequence stars.

M Class

Class M is by far the most common class. Over 78% of stars are red dwarfs, such as Proxima Centauri. M is also host to most giants and some supergiants such as Antares and Betelgeuse, as well as Mira variables. The Late-M group hold hotter Brown Dwarfs that are above the L spectrum. This is usually in the range of M6.5 to M9.5. The spectrum of an M star shows lines belonging to molecules and all neutral metals but hydrogen are usually absent. Titanium oxide can be strong in M stars.

W Class

Class W or WR represents the superluminous Wolf-Rayet stars, notably unusual since they have mostly helium in their atmospheres instead of hydrogen. They are thought to be dying supergiants with their hydrogen layer blown away by hot stellar winds caused by their high temperatures, thereby directly exposing their hot helium shell. Class W is subdivided into subclasses WC, WN, and WO according to the dominance of carbon, nitrogen, or oxygen in their spectra (and outer layers). W class stars range up to 70,000 K.

Intermediary between the genuine Wolf-Rayet's and ordinary hot stars of classes O and early B, there are OC, ON, BC and BN stars. They seem to constitute a short continuum from the Wolf-Rayet's into the ordinary OBs.

L Class

Class L, dwarfs get their designation because they are cooler than M stars and L is the remaining letter alphabetically closest to M. L does not mean Lithium Dwarf; a large fraction of these stars do not have Lithium in their spectra. Some of these objects are of substellar mass (do not support fusion) and some are not, so collectively this class of objects should be referred to as "L dwarfs", not "L stars." They are a very dark red in color and brightest in infrared. Their gas is cool enough to allow metal hydrides and alkali metals to be prominent in their spectra. They range from 1300 to 2500 K.

T Class

Class T stars are very young and low density stars often found in the interstellar clouds they were born in. These are stars barely big enough to be stars and others that are substellar, being of the brown dwarf variety. They are black, emitting little or no visible light but being strongest in infrared. Their surface temperature is a stark contrast to the fifty thousand kelvins or more for Class O stars, being merely up to 1,000 K. Complex molecules can form, evidenced by the strong methane lines in their spectra.

Y Class

Class Y stars are expected to be much cooler than T-dwarfs. None have been found as of yet, but they have been modeled. These are ultra-cool brown dwarves.

C Class

Originally classified as R and N stars, these are also known as 'carbon stars'. These are red giants, near the end of their lives, in which there is an excess of carbon in the atmosphere. The old R and N classes ran parallel to the normal classification system from roughly mid G to late M. These have more recently been remapped into a unified carbon classifier C, with N0 starting at roughly C6. Another subset of cool carbon stars are the J-type stars, which are characterized by the strong presence of molecules of ^{13}CN in addition to those of ^{12}CN. A few dwarf (that is, main sequence) carbon stars are known, but the overwhelming majority of known carbon stars are giants or supergiants.

S Class

Class S stars have ZrO lines in addition to (or, rarely, instead of) those of TiO, and are in between the Class M stars and the carbon stars. S stars have excess amounts of zirconium and other elements produced by the s-process, and have their carbon and oxygen abundances closer to equal than is the case for M stars. The latter condition results in both C and O being locked up almost entirely in CO molecules. For stars cool enough for CO to form that molecule tends to "eat up" all of whichever element is less abundant, resulting in "leftover oxygen" (which becomes available to form TiO) in stars of normal composition, "leftover carbon" (which becomes available to form the diatomic carbon molecules) in carbon stars, and "leftover nothing" in the S stars. The relation between these stars and the ordinary M stars indicates a continuum of carbon abundance. Like carbon stars, nearly all known S stars are giants or supergiants.

MS and SC Class

In between the M class and the S class, border cases are named MS stars. In a similar way border cases between the S class and the C-N class are named SC or CS. The sequence M – MS – S – SC – N is believed to be a sequence of increased carbon abundance with age for carbon stars in the asymptotic giant branch.

D Class

The class D is sometimes used for white dwarfs, the state most stars end their life in. Class D is further divided into classes DA, DB, DC, DO, DZ, and DQ. The letters are not related to the letters used in the classification of true stars, but instead indicate the composition of the white dwarf's outer layer or "atmosphere".
The white dwarf classes are as follows:

- DA: a hydrogen-rich "atmosphere" or outer layer, indicated by strong Balmer hydrogen spectral lines.
- DB: a neutral helium-rich "atmosphere" or outer layer, indicated by neutral helium spectral lines, (He I lines).
- DO: an ionized helium-rich "atmosphere" or outer layer, indicated by ionized helium spectral lines, (He II lines).
- DC: no strong spectral lines indicating one of the above categories.
- DQ: a carbon-rich "atmosphere" or outer layer, indicated by atomic or molecular carbon lines.
- DZ: a 'metal'-rich "atmosphere" or outer layer, indicated by magnesium, calcium, and/or iron lines, (Ca I, Ca II H and K, Mg I, Fe I, Na I).

- DX: spectral lines are insufficiently clear to classify into one of the above categories.

All class D stars use the same sequence from 1 to 9, with 1 indicating a temperature above 37,500 K and 9 indicating a temperature below 5,500 K. (The number is by definition equal to Teff = 50,400 K.)

Extended White Dwarf Class

- DAB: a hydrogen- and neutral helium-rich white dwarf.
- DAO: a hydrogen- and ionized helium-rich white dwarf.
- DAZ: a hydrogen-rich cool metallic white dwarf.
- DBZ: a helium-rich cool metallic white dwarf.
- DAV or zz Ceti: a hydrogen-rich pulsating white dwarf.
- DBV or V777 Her: a helium-rich pulsating white dwarf
- DOV or PG 1159: a helium-rich pulsating white dwarf.

P & Q Class

Finally, the classes P and Q are occasionally used for certain non-stellar objects. Type P objects are planetary nebulae and type Q objects are novae.

Every star generates a stellar wind of particles that causes a continual outflow of gas into space. For most stars, the amount of mass lost is negligible. The Sun loses 10^{-14} solar masses every year, or about 0.01% of its total mass over its entire lifespan. However very massive stars can lose 10^{-7} to 10^{-5} solar masses each year, significantly affecting their evolution. Stars that begin with more than 50 solar masses can lose over half their total mass while they remain on the main sequence.

The duration that a star spends on the main sequence depends primarily on the amount of fuel it has to burn and the rate at which it burns that fuel. In other words, its initial mass and its luminosity. For the Sun, this is estimated to be about 10^{10} years (10 billion). Large stars burn their fuel very rapidly and are short-lived. Small stars (called red dwarfs) burn their fuel very slowly and last tens to hundreds of billions of years. At the end of their lives, they simply become dimmer and dimmer, fading into black dwarfs. However, since the lifespan of such stars is greater than the current age of the universe (13.7 billion years), no black dwarfs are expected to exist yet.

Besides mass, the portion of elements heavier than helium can play a significant role in the evolution of stars. In astronomy all elements heavier than helium are considered a "metal", and the chemical concentration of these elements is called the metallicity. The metallicity can influence the duration that a star will burn its fuel, control the formation of magnetic fields and modify the strength of the stellar wind. Older, population II stars have substantially less metallicity than the younger, population I stars due to the composition of the molecular clouds from which they formed. (Over time these clouds become increasingly enriched in heavier elements as older stars die and shed portions of their atmospheres.)

<u>Post-Main Sequence</u>

As stars of at least 0.4 solar masses exhaust their supply of hydrogen at their core, their outer layers expand and cool to form a red giant. In about 5 billion years, when the Sun is a red giant, it will be so large that it will consume Mercury and possibly Venus.

Models predict that the Sun will expand out to about 99% of the distance to the Earth's present orbit (1 astronomical unit, or AU). By that time, however, the orbit of the Earth will expand to about 1.7 AUs due to mass loss by the Sun and thus the Earth will escape envelopment. However, the Earth will be stripped of its oceans and atmosphere as the Sun's luminosity increases several thousand fold.

In a red giant, hydrogen fusion proceeds in a shell-layer surrounding the core. Eventually the core is compressed enough to start helium fusion, and the star now gradually shrinks in radius and increases its surface temperature.

After the star has consumed the helium at the core, fusion continues in a shell around a hot core of carbon and oxygen. The star now follows an evolutionary path that parallels the original red giant phase, but at a higher surface temperature.

Massive Stars

During their helium-burning phase, very high mass stars with more than nine solar masses expand to form red supergiants. Once this fuel is exhausted at the core, they can continue to fuse elements heavier than helium. The core contracts until the temperature and pressure are sufficient to fuse carbon. This process continues, with the successive stages being fueled by oxygen, neon, silicon, and sulfur. Near the end of the star's life, fusion can occur along a series of onion-layer shells within the star. Each shell fuses a different element, with the outermost shell fusing hydrogen; the next shell fusing helium, and so forth.

The final stage is reached when the star begins producing iron. Since iron nuclei are more tightly bound than any heavier nuclei, if they are fused they do not release energy - the process would, on the contrary, consume energy. Likewise, since they are more tightly bound than all lighter nuclei, energy cannot be released by fission. In relatively old, very massive stars, a large core of inert iron will accumulate in the center of the star. The heavier elements in these stars can work their way up to the surface, forming evolved objects known as Wolf-Rayet stars that have a dense stellar wind which sheds the outer atmosphere.

Stellar Collapse

An evolved, average-size star will now shed its outer layers as a planetary nebula. If what remains after the outer atmosphere has been shed is less than 1.4 solar masses, it shrinks to a relatively tiny object (about the size of Earth) that is not massive enough for further compression to take place, known as a white dwarf. The electron-degenerate matter inside a white dwarf is no longer a plasma, even though stars are generally referred to as being spheres of plasma. White dwarfs will eventually fade into black dwarfs over a very long stretch of time.

In larger stars, fusion continues until the iron core has grown so large that it can no longer support its own mass (more than 1.4 solar masses). This core will suddenly collapse as its electrons are driven into its protons, forming neutrons and neutrinos in a burst of inverse beta decay, or electron capture. The shockwave formed by this sudden collapse causes the rest of the star to explode in a supernova. Supernovae are so bright that they may briefly outshine the star's entire home galaxy. When they occur within the Milky Way, supernovae have historically been observed by naked-eye observers as "new stars" where none existed before.

Most of the matter in the star is blown away by the supernovae explosion (forming nebulae such as the Crab Nebula) and what remains will be a neutron star (which sometimes manifests itself as a pulsar or X-ray burster) or, in the case of the largest stars (large enough to leave a stellar remnant greater than roughly 4 solar masses), a black hole. In a neutron star the matter is in a state known as neutron-degenerate matter, with a more exotic form of degenerate matter, QCD matter, possibly present in the core. Within a black hole the matter is in a state that is not currently understood.

The blown-off outer layers of dying stars include heavy elements which may be recycled during new star formation. These heavy elements allow the formation of rocky planets. The outflow from supernovae and the stellar wind of large stars play an important part in shaping the interstellar medium

Stellar Distribution

The Pleiades, an open cluster of stars in the constellation of Taurus. *NASA* photo.

It has been a long-held assumption that the majority of stars occur in gravitationally-bound, multiple-star systems, forming binary stars. This is particularly true for very massive O and B class stars, where 80% of the systems are believed to be multiple. However the portion of single star systems increases for smaller stars, so that only 25% of red dwarfs are known to have stellar companions. As 85% of all stars are red dwarfs, most stars in the Milky Way are likely single from birth.

Larger groups called star clusters also exist. These range from loose stellar associations with only a few stars, up to enormous globular clusters with hundreds of thousands of stars.

Stars are not spread uniformly across the universe, but are normally grouped into galaxies along with interstellar gas and dust. A typical galaxy contains hundreds of billions of stars, and there are more than 100 billion (1011) galaxies in the observable universe. While it is often believed that stars only exist within galaxies, intergalactic stars have been discovered.

Astronomers estimate that there are at least 70 sextillion (7×1022) stars in the known universe. That is 230 billion times as many as the 300 billion in our own Milky Way.

The nearest star to the Earth, apart from the Sun, is Proxima Centauri, which is 39.9 trillion (1012) kilometers, or 4.2 light-years away. Light from Proxima Centauri takes 4.2 years to reach Earth. Traveling at the orbital speed of the Space Shuttle (5 miles per second - almost 30,000 kilometers per hour), it would take about 150,000 years to get

there. Distances like this are typical inside galactic discs, including the vicinity of the solar system. Stars can be much closer to each other in the centers of galaxies and in globular clusters, or much farther apart in galactic halos.

Because of their low density, collisions of stars in the galaxy are thought to be rare. However in dense regions such as the core of globular clusters or the galactic center, collisions can be more common. Such collisions can produce what are known as blue stragglers. These abnormal stars have a higher surface temperature than the other main sequence stars in the cluster with the same luminosity.

Characteristics

Almost everything about a star is determined by its initial mass, including essential characteristics such as luminosity and size, as well as the star's evolution, lifespan, and eventual fate.

Age

Many stars are between 1 billion and 10 billion years old. Some stars may even be close to 13.7 billion years old - the observed age of the universe. The more massive the star, the shorter its lifespan, primarily because massive stars have greater pressure on their cores, causing them to burn hydrogen more rapidly. The most massive stars last an average of about one million years, while stars of minimum mass (red dwarfs) burn their fuel very slowly and last tens to hundreds of billions of years.

Chemical Composition

When stars form they are composed of about 70% hydrogen and 28% helium, as measured by mass, with a small fraction of heavier elements. Typically the portion of heavy elements is measured in terms of the iron content of the stellar atmosphere, as iron is a common element and its absorption lines are relatively easy to measure. Because the molecular clouds where stars form are steadily enriched by heavier elements from supernovae explosions, a measurement of the chemical composition of a star can be used to infer its age. The portion of heavier elements may also be an indicator of the likelihood that the star has a planetary system.

The star with the lowest iron content ever measured is the dwarf HE1327-2326, with only 1/200,000th the iron content of the Sun.

Diameter

Due to their great distance from the Earth, all stars except the Sun appear to the human eye as shining points in the night sky that twinkle because of the effect of the Earth's atmosphere. The disks of stars are much too small in angular size to be observed with current ground-based optical telescopes, and so Interferometer telescopes are required in order to produce images of these objects. The Sun is also a star, but it is close enough to the Earth to appear as a disk instead, and to provide daylight. Other than the Sun, the star with the largest apparent size is R Doradus, with an angular diameter of only 0.057 arcseconds.

Stars range in size from neutron stars, which vary anywhere from 20 to 40 km in diameter, to supergiants like Betelgeuse in the Orion constellation, which has a diameter approximately 650 times larger than the Sun - about 0.9 billion kilometers. However, Betelgeuse has a much lower density than the Sun.

Kinematics

The motion of a star relative to the Sun can provide useful information about the origin and age of a star, as well as the structure and evolution of the surrounding galaxy.

The proper motion of a star is the traverse velocity across the sky. This is determined by precise astrometric measurements in units of milli-arc seconds (mas) per year. By determining the parallax of a star, the proper motion can then be converted into units of velocity. Stars with high rates of proper motion are likely to be relatively close to the Sun, making them good candidates for parallax measurements.

The radial velocity is the movement of the star toward or away from the Sun. This is determined by measurements in the Doppler shift of spectral lines, and is given in units of km/s.

Once both rates of movement are known, the space velocity of the star relative to the Sun or the galaxy can be computed. Among nearby stars, it has been found that population I stars have generally lower velocities than older, population II stars. The latter have elliptical orbits that are inclined to the plane of the galaxy. Comparison of the kinematics of nearby stars has also led to the identification of stellar associations. These are most likely groups of stars that share a common point of origin in giant molecular clouds.

Mass

One of the most massive stars known is Eta Carinae, with 100 - 150 times as much mass as the Sun; its lifespan is very short - only several million years at most. A recent study of the Arches cluster suggests that 150 solar masses is the upper limit for stars in the current era of the universe. The reason for this limit is not precisely known, but it is partially due to the Eddington luminosity which defines the maximum amount of luminosity that can pass through the atmosphere of a star without ejecting the gases into space.

The first stars to form after the Big Bang may have been larger, up to 300 solar masses or more, due to the complete absence of elements heavier than lithium in their composition. This generation of supermassive, population III stars is long extinct, however, and currently only theoretical.

With a mass only 93 times that of Jupiter, AB Doradus C, a companion to AB Doradus A, is the smallest known star undergoing nuclear fusion in its core. For stars with similar metallicity to the Sun, the theoretical minimum mass the star can have, and still undergo fusion at the core, is estimated to be about 75 times the mass of Jupiter. When the metallicity is very low, however, a recent study of the faintest stars found that the minimum star size seems to be about 8.3% of the solar mass, or about 87 times the mass of Jupiter. Smaller bodies are called brown dwarfs, which occupy a poorly-defined grey area between stars and gas giants.

The combination of the radius and the mass of a star determines the surface gravity. Giant stars have a much lower surface gravity than main sequence stars, while the opposite is the case for degenerate, compact stars such as white dwarfs. The surface gravity can influence the appearance of a star's spectrum, with higher gravity causing a broadening of the absorption lines.

Rotation

The rotation rate of stars can be approximated through spectroscopic measurement, or more exactly determined by tracking the rotation rate of starspots. Young stars can have a rapid rate of rotation greater than 100 km/s at the equator. The B-

class star Achernar, for example, has an equatorial rotation velocity of about 225 km/s or greater, giving it an equatorial diameter that is more than 50% larger than the distance between the poles. This rate of rotation is just below the critical velocity of 300 km/s where the star would break apart. By contrast, the Sun only rotates once every 25 – 35 days, with an equatorial velocity of 1.994 km/s. The star's magnetic field and the stellar wind serve to slow down a main sequence star's rate of rotation by a significant amount as it evolves on the main sequence.

Degenerate stars have contracted into a compact mass, resulting in a rapid rate of rotation. However they have relatively low rates of rotation compared to what would be expected by conservation of angular momentum - the tendency of a rotating body to compensate for a contraction in size by increasing its rate of spin. A large portion of the star's angular momentum is dissipated as a result of mass loss through the stellar wind. In spite of this, the rate of rotation for a pulsar can be very rapid. The pulsar at the heart of the Crab nebula, for example, rotates 30 times per second. The rotation rate of the pulsar will gradually slow due to the emission of radiation

Temperature

The surface temperature of a main sequence star is determined by the rate of energy production at the core and the radius of the star. Massive stars can have surface temperatures of 50,000 K. Smaller stars such as the Sun have surface temperatures of a few thousand degrees. Red giants have relatively low surface temperatures of about 3,600 K, but they also have a high luminosity due to their large exterior surface area.

The stellar temperature will determine the rate of energization or ionization of different elements, resulting in characteristic absorption lines in the spectrum. The surface temperature of a star, along with its visual absolute magnitude and absorption features, is used to classify a star (see classification below).

Radiation

The energy produced by stars, as a by-product of nuclear fusion, radiates into space as both electromagnetic radiation and particle radiation. The particle radiation emitted by a star is manifested as the stellar wind (which exists as a steady stream of electrically charged particles, such as free protons, alpha particles, and beta particles, emanating from the star’s outer layers) and as a steady stream of neutrinos emanating from the star’s core.

The production of energy at the core is the reason why stars shine so brightly: every time two or more atomic nuclei of one element fuse together to form an atomic nucleus of a new heavier element, gamma ray photons are released from the nuclear fusion reaction. This energy is converted to other forms of electromagnetic energy, including visible light, by the time it reaches the star’s outer layers.

The color of a star, as determined by the peak frequency of the visible light, depends on the temperature of the star’s outer layers, including its photosphere. Besides visible light, stars also emit forms of electromagnetic radiation that are invisible to the human eye. In fact, stellar electromagnetic radiation spans the entire electromagnetic spectrum, from the longest wavelengths of radio waves and infrared to the shortest wavelengths of ultraviolet, X-rays, and gamma rays. All components of stellar electromagnetic radiation, both visible and invisible, are typically significant.

Using the stellar spectrum, astronomers can also determine the surface temperature, surface gravity, metallicity and rotational velocity of a star. If the distance of

the star is known, such as by measuring the parallax, then the luminosity of the star can be derived. The mass, radius, surface gravity, and rotation period can then be estimated based on stellar models. (Mass can be measured directly for stars in binary systems. The technique of gravitational microlensing will also yield the mass of a star.) With these parameters, astronomers can also estimate the age of the star.

Luminosity

In astronomy, luminosity is the amount of light, and other forms of radiant energy, a star radiates per unit of time. The luminosity of a star is determined by the radius and the surface temperature.

Surface patches with a lower temperature and luminosity than average are known as starspots. Small, dwarf stars such as the Sun generally have essentially featureless disks with only small starspots. Larger, giant stars have much bigger, much more obvious starspots, and they also exhibit strong stellar limb darkening. That is, the brightness decreases towards the edge of the stellar disk. Red dwarf flare stars such as UV Ceti may also possess prominent starspot features.

Magnitude

The apparent brightness of a star is measured by its apparent magnitude, which is the brightness of a star with respect to the star's luminosity, distance from Earth, and the altering of the star's light as it passes through Earth's atmosphere.

Number of stars brighter than magnitude

Apparent magnitude	Number of Stars*
0	4
1	15
2	48
3	171
4	513
5	1,602
6	4,800
7	14,000

* Discovered as of 2006-08-03

Intrinsic or absolute magnitude is what the apparent magnitude a star would be if the distance between the Earth and the star were 10 parsecs (32.6 light-years), and it is directly related to a star's luminosity.

Both the apparent and absolute magnitude scales are logarithmic units: one whole number difference in magnitude is equal to a brightness variation of about 2.5 times (the 5th root of 100 or approximately 2.512). This means that a first magnitude (+1.00) star is about 2.5 times brighter than a second magnitude (+2.00) star, and approximately 100 times brighter than a sixth magnitude (+6.00) star. The faintest stars visible to the naked eye under good seeing conditions are about magnitude +6.

On both apparent and absolute magnitude scales, the smaller the magnitude number, the brighter the star; the larger the magnitude number, the fainter. The brightest stars, on either scale, have negative magnitude numbers. The variation in brightness

between two stars is calculated by subtracting the magnitude number of the brighter star (mb) from the magnitude number of the fainter star (mf), then using the difference as an exponent for the base number 2.512; that is to say:

$$\Delta m = mf - mb$$

$$2.512^{\Delta m} = \text{variation in brightness}$$

Relative to both luminosity and distance from Earth, absolute magnitude (M) and apparent magnitude (m) are not equivalent for an individual star; for example, the bright star Sirius has an apparent magnitude of −1.44, but it has an absolute magnitude of +1.41.

The Sun has an apparent magnitude of −26.7, but its absolute magnitude is only +4.83. Sirius, the brightest star in the night sky as seen from Earth, is approximately 23 times more luminous than the Sun, while Canopus, the second brightest star in the night sky with an absolute magnitude of −5.53, is approximately 14,000 times more luminous than the Sun. Despite Canopus being vastly more luminous than Sirius, however, Sirius appears brighter than Canopus. This is because Sirius is merely 8.6 light-years from the Earth, while Canopus is much farther away at a distance of 310 light-years.

As of 2006, the star with the highest known absolute magnitude is LBV 1806-20, with a magnitude of -14.2. This star is at least 5,000,000 times more luminous than the Sun. The least luminous stars that are currently known are located in the NGC 6397 cluster. The faintest red dwarfs in the cluster were magnitude 26, while a 28th magnitude white dwarf was also discovered. These faint stars are so dim that their light is as bright as a birthday candle on the Moon when viewed from the Earth.

Stellar Classification

There are different classifications of stars according to their spectra ranging from type **O**, which are very hot, to **M**, which are so cool that molecules may form in their atmospheres. The main classifications in order of decreasing surface temperature are **O, B, A, F, G, K**, and **M**. A variety of rare spectral types have special classifications. The most common of these are types **L** and **T**, which classify the coldest low-mass stars and brown dwarfs.

Each letter has 10 sub-classifications numbered (hottest to coldest) from **0** to **9**. This system matches closely with temperature, but breaks down at the extreme hottest end; class **O0** and **O1** stars might not exist.

In addition, stars may be classified by the *luminosity effects* found in their spectral lines, which correspond to their spatial size and is determined by the surface gravity. These range from **0** (hypergiants) through **III** (giants) to **V** (main sequence dwarfs) and **VII** (white dwarfs). Most stars fall into the main sequence, which consists of ordinary hydrogen-burning stars. These fall along a narrow band when graphed according to their absolute magnitude and spectral type. Our Sun is a main sequence **G2V** (yellow dwarf), being of intermediate temperature and ordinary size.

Additional nomenclature, in the form of lower-case letters, can follow the spectral type to indicate peculiar features of the spectrum. For example, an "*e*" can indicate the presence of emission lines; "*m*" represents unusually strong levels of metals, and "*var*" can mean variations in the spectral type.

White dwarf stars have their own class that begins with the letter **D**. This is further sub-divided into the classes **DA**, **DB**, **DC**, **DO**, **DZ**, and **DQ**, depending on the

types of prominent lines found in the spectrum. This is followed by a numerical value that indicates the temperature index.

Surface Temperature Ranges for Different Stellar Classes

Class	Temperature	Sample star
O	33,000 K or more	Zeta Ophiuchi
B	10,500–30,000 K	Rigel
A	7,500–10,000 K	Altair
F	6,000–7,200 K	Procyon A
G	5,500–6,000 K	Sun
K	4,000–5,250 K	Epsilon Indi
M	2,600–3,850 K	Proxima Centauri

Variable Stars

Variable stars have periodic or random changes in luminosity because of intrinsic or extrinsic properties. Of the intrinsically variable stars, the primary types can be subdivided into three principal groups.

Pulsating variables are stars that vary in radius over time, expanding and contracting as a result of the stellar aging process. This category includes Cepheid and cepheid-like stars, and long-period variables such as Mira.

Eruptive variables are stars that experience sudden increases in luminosity because of flares or mass ejection events. This group includes protostars, Wolf-Rayet stars, and Flare stars, as well as giant and supergiant stars.

Cataclysmic or explosive variables undergo a dramatic change in their properties. This group includes novae and supernovae. A binary star system that includes a nearby white dwarf can produce certain types of these spectacular stellar explosions, including the nova and a Type 1a supernova. The explosion is created when the white dwarf accretes hydrogen from the companion star, building up mass until the hydrogen undergoes fusion. Some novae are also recurrent, having periodic outbursts of moderate amplitude.

Stars can also vary in luminosity because of extrinsic factors, such as eclipsing binaries, as well as rotating stars that produce extreme starspots. A notable example of an eclipsing binary is Algol, which regularly varies in magnitude from 2.3 to 3.5 over a period of 2.87 days.

Multiple Stars

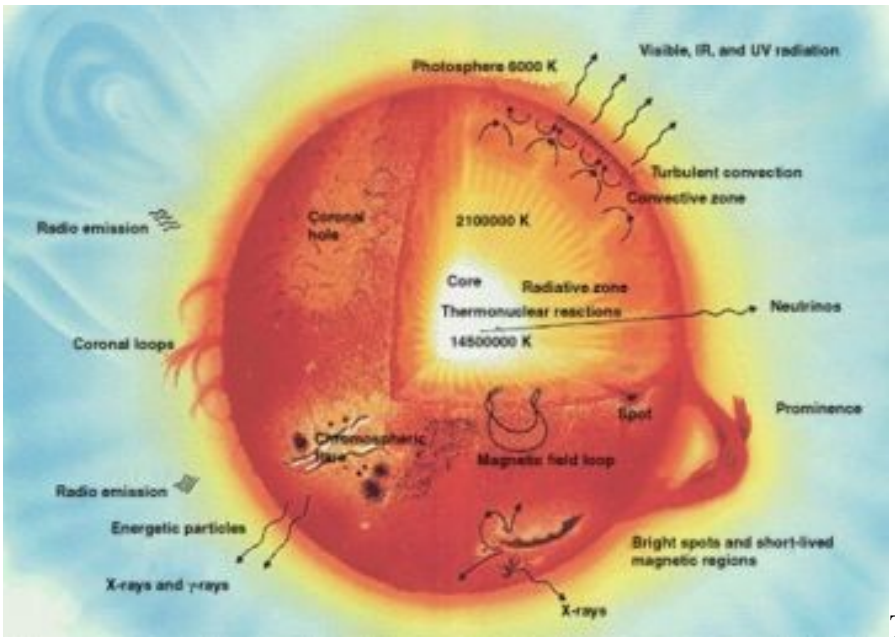
Star systems with two or more stars is quite common; indeed it is believed single-star systems like our own are on the rare side. Approximately 25-50% of star systems are binary stars, with about 10% of those having three or more stars.

Structure of a Star

The interior of a stable, main sequence star is in a state of equilibrium in which the forces in any small volume almost exactly counterbalance each other. The balancing forces consist of inward directed gravitational force and the opposing pressure from the thermal energy of the plasma gas. For these forces to balance out, the temperature at the core of a typical star has to be on the order of 107 K or higher. The resulting temperature and pressure at the hydrogen-burning core of a main sequence star are sufficient for nuclear fusion to occur, and for sufficient energy to be produced to prevent further collapse of the star.

As atomic nuclei are fused in the core, they emit energy in the form of gamma rays. These photons interact with the surrounding plasma, adding to the thermal energy at the core. Stars on the main sequence convert hydrogen into helium, creating a slowly but steadily increasing proportion of helium in the core. Eventually the helium content becomes predominant and energy production ceases at the core. Instead, for stars of greater than 0.4 solar masses, fusion occurs in a slowly expanding shell around the degenerate helium core.

In addition to hydrostatic equilibrium, the interior of a stable star will also maintain an energy balance of thermal equilibrium. There is a radial temperature gradient throughout the interior that results in a flux of energy flowing toward the exterior. The outgoing flux of energy leaving any layer within the star will exactly match the incoming flux from below.



This diagram shows a cross-section of a solar-type star. NASA image

The radiation zone is the region within the stellar interior where radiative transfer is sufficiently efficient to maintain the flux of energy. In this region the plasma will not be perturbed and any mass motions will die out. If this is not the case, however, then the plasma becomes unstable and convection will occur, forming a convection zone. This can occur, for example, in regions where very high energy fluxes occur, such near the core or in areas with high opacity as in the outer envelope.

The occurrence of convection in the outer envelope of a main sequence star depends on the spectral type. Stars with several times the mass of the Sun have a convection zone deep within the interior and a radiative zone in the outer layers. Smaller stars such as the Sun are just the opposite, with the convective zone located in the outer layers. Red dwarf stars with less than 0.4 solar masses are convective throughout, which prevents the accumulation of a helium core. For most stars the convective zones will also vary over time as the star ages and the constitution of the interior is modified.

The portion of a main sequence star that is visible to an observer is called the photosphere. This is the layer at which the plasma gas of the star becomes transparent to photons of light. From here, the energy generated at the core becomes free to propagate out into space. It is within the photosphere that sun spots, or regions of lower than average temperature, appear.

Above the level of the photosphere is the stellar atmosphere. In a main sequence star such as the Sun, the lowest level of the atmosphere is the thin chromosphere region, where spicules appear and stellar flares begin. This is surrounded by a transition region, where the temperature rapidly increases within a distance of only 100 km. Beyond this is the corona, a volume of super-heated plasma that can extend outward to several million kilometres. The existence of a corona appears to be dependent on a convective zone in the outer layers of the star. Despite its high temperature, the corona emits very little light. The corona region of the Sun is normally only visible during a solar eclipse.

From the corona, a stellar wind of plasma particles expands outward from the star, propagating until it interacts with the interstellar medium.

Nuclear Fusion Reaction Pathways

A variety of different nuclear fusion reactions take place inside the cores of stars, depending upon their mass and composition, as part of stellar nucleosynthesis. The net mass of the fused atomic nuclei is smaller than the sum of the constituents. This lost mass is converted into energy, according to the mass-energy relationship $E=mc^2$.

The hydrogen fusion process is temperature-sensitive, so a moderate increase in the core temperature will result in a significant increase in the fusion rate. As a result the core temperature of main sequence stars only varies from 4 million K for a small M-class star to 40 million K for a massive O-class star.

In the Sun, with a 107 K core, hydrogen fuses to form helium in the proton-proton chain reaction:

$$4{}^1\mathrm{H} \rightarrow {}^2\mathrm{H} + 2e^+ + 2\nu_e \ (4.0\ \mathrm{MeV} + 1.0\ \mathrm{MeV})$$
$${}^2\mathrm{H} + {}^2\mathrm{H} \rightarrow {}^3\mathrm{He} + 2\gamma \ (5.5\ \mathrm{MeV})$$
$${}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + {}^1\mathrm{H} \ (12.9\ \mathrm{MeV})$$

These reactions result in the overall reaction:

$$4{}^1\mathrm{H} \rightarrow {}^4\mathrm{He} + 2e^+ + 2\gamma + 2\nu_e \ (26.7\ \mathrm{MeV})$$

where e^+ is a positron, γ is a gamma ray photon, ν_e is a neutrino, and H and He are isotopes of hydrogen and helium, respectively. The energy released by this reaction is in millions of electron volts, which is actually only a tiny amount of energy. However enormous numbers of these reactions occur constantly, producing all the energy necessary to sustain the star's radiation output.

In more massive stars, helium is produced in a cycle of reactions catalyzed by carbon—the carbon-nitrogen-oxygen cycle.

In evolved stars with cores at 108 K and masses between 0.5 and 10 solar masses, helium can be transformed into carbon in the triple-alpha process that uses the intermediate element beryllium:

$$4\mathrm{He} + 4\mathrm{He} + 92\ \mathrm{keV} \rightarrow 8^*\mathrm{Be}$$
$$4\mathrm{He} + 8^*\mathrm{Be} + 67\ \mathrm{keV} \rightarrow 12^*\mathrm{C}$$
$$12^*\mathrm{C} \rightarrow 12\mathrm{C} + \gamma + 7.4\ \mathrm{MeV}$$

For an overall reaction of:

$$3 4\mathrm{He} \rightarrow 12\mathrm{C} + \gamma + 7.2\ \mathrm{MeV}$$

In massive stars, heavier elements can also be burned in a contracting core through the Neon burning process and Oxygen burning process. The final stage in the stellar nucleosynthesis process is the Silicon burning process that results in the production of the stable isotope iron-56. Fusion can not proceed any further except through an endothermic process, and so further energy can only be produced through gravitational collapse.

The example below shows the amount of time required for a star of 20 solar masses to consume all of its nuclear fuel. As an O-class main sequence star, it would be 8 times the solar radius and 62,000 times the Sun's luminosity.

Fuel material	Temperature (million kelvins)	Density (kg/cm^3)	Burn duration τ
H	37	0.0045	8.1 million years
He	188	0.97	1.2 million years

C	870	170	976 years
Ne	1,570	3,100	0.6 years
O	1,980	5,550	1.25 years
S/Si	3,340	33,400	11.5 days

Unusual Stars

Not all stars fall into the basic model above. These are included as possible research plots or even possible disasters. Most of these types of stars cannot support a star system due to their natures.

Blue Straggler

Blue stragglers are stars in open or globular clusters that are hotter and bluer than other cluster stars having the same luminosity. Thus, they are separate from other stars on the cluster's Hertzsprung-Russell diagram. Blue straggler stars appear to violate standard theories of stellar evolution, in which all stars born at the same time should lie on a clearly defined curve in the Hertzsprung-Russell diagram, with their positions on that curve determined solely by their initial mass. Since blue stragglers often lie well off this curve, they may undergo abnormal stellar evolution.

The cause of this is not yet clearly known, but the leading hypothesis is that they are current or former binary stars that are in the process of merging or have already done so. The merger of two stars would create a single star with larger mass, making it hotter and more luminous than stars of a similar age. If this theory is correct, then blue stragglers would no longer cause a problem for stellar evolution theory; the resulting star would have more hydrogen in its core making it behave like a much younger star. There is evidence in favor of this view, notably that blue straggler stars appear to be much more common in dense regions of clusters, especially in the cores of globular clusters. Since there are more stars per unit volume, collisions and close-encounters are far more likely in clusters than among field stars.

One way to test this hypothesis is to study the pulsations of variable blue straggler stars. The asteroseismological properties of merged stars may be measurably different from those of normal pulsating variables of similar mass and luminosity. However, the measurement of pulsations is very difficult, given the scarcity of variable blue stragglers, the small photometric amplitudes of their pulsations, and the crowded fields these stars are often found in.

Hypervelocity Stars

Hypervelocity stars (HVSs) are stars moving with high velocity relative to the galaxy, which have or will eventually escape from the Galaxy, hence also the name Exiled Stars. Ordinary stars in the galaxy have velocities not exceeding 200 km/s, while hypervelocity stars are moving at several times this speed.

Currently, seven HVSs are known. One of them possibly originating from the Large Magellanic Cloud, this one discovered by H. Edelmann et al. Warren Brown from the Harvard-Smithsonian Center for Astrophysics discovered the first one in 2005. In 2006 two more have been discovered by Warren Brown et al. Their velocities are 558±12 and 638±12 km/s.

It is believed that around 1000 HVSs exist in our Galaxy. Considering the large number of stars in the Milky Way, this is only a tiny fraction.

HVSs are believed to originate by close encounters of binary stars to the black hole in the center of the Milky Way. One of the two partners is captured by the black hole, while the other escapes with high velocity.

Known HVSs:

- HV 1 (SDSS J090745.0+24507) (a.k.a. The Outcast Star)
- HV 2 (SDSS J093320.86+441705.4) (US 708)
- HV 3 (HE 0437-5439) - possibly from the Large Magellanic Cloud
- HV 4 (SDSS J091301.00+305120.0)
- HV 5 (SDSS J091759.42+672238.7)
- HV 6 (SDSS J110557.45+093439.5)
- HV 7 (SDSS J113312.12+010824.9)

Neutron Star

A neutron star is one of the few possible endpoints of stellar evolution. A neutron star is formed from the collapsed remnant of a massive star after a Type II, Type Ib, or Type Ic supernova.

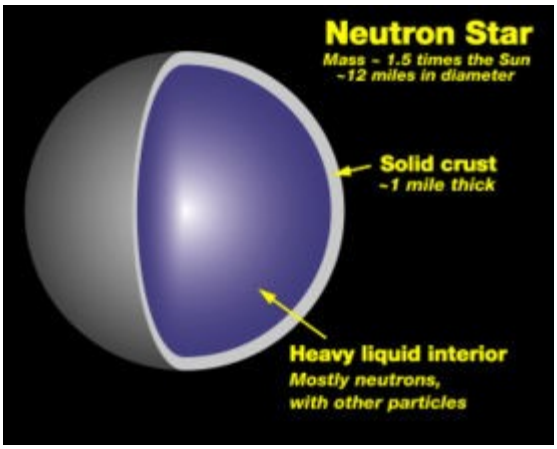
A typical neutron star has a mass between 1.35 to about 2.1 solar masses, with a corresponding radius between 20 and 10 km (they shrink as their mass increases) — 30,000 to 70,000 times smaller than the Sun. Thus, neutron stars have densities of 8×1013 to 2×1015 g/cm³, about the density of an atomic nucleus. Compact stars of less than 1.44 solar masses, the Chandrasekhar limit, are white dwarfs; above three to five solar masses (the Tolman-Oppenheimer-Volkoff limit), gravitational collapse occurs, inevitably producing a black hole.

Since a neutron star retains most of the angular momentum of its parent star but has only a tiny fraction of its parent's radius, the moment of inertia decreases sharply causing a rotational acceleration to a very high rotation speed, with one revolution taking anywhere from one seven-hundredth of a second to thirty seconds. The neutron star's compactness also gives it high surface gravity, 2×1011 to 3×1012 times stronger than that of Earth. One of the measures for the gravity is the escape velocity, the velocity needed for an object to escape from the gravitational field to infinite distance. For a neutron star, such velocities are typically 150,000 km/s, about 1/2 of the velocity of light. Conversely, matter falling onto the surface of a neutron star would strike the star also at 150,000 km/s.

Structure

Current understanding of the structure of neutron stars is defined by existing mathematical models. On the basis of current models, the matter at the surface of a neutron star is composed of ordinary atomic nuclei as well as electrons. The "atmosphere" of the star is roughly one meter thick, below which one encounters a solid "crust". Proceeding inward, one encounters nuclei with ever increasing numbers of neutrons; such nuclei would quickly decay on Earth, but are kept stable by tremendous pressures. Proceeding deeper, one comes to a point called neutron drip where free neutrons leak out of nuclei. In this region, there are nuclei, free electrons, and free neutrons. The nuclei become smaller and smaller until the core is reached, by definition the point where they disappear altogether. The exact nature of the superdense matter in the core is still not well understood. While this theoretical substance is referred to as

neutronium in science fiction and popular literature, the term "neutronium" is rarely used in scientific publications, due to ambiguity over its meaning. The term neutron-degenerate matter is sometimes used, though not universally as the term incorporates assumptions about the nature of neutron star core material. Neutron star core material could be a superfluid mixture of neutrons with a few protons and electrons, or it could incorporate high-energy particles like pions and kaons in addition to neutrons, or it could be composed of strange matter incorporating quarks heavier than up and down quarks, or it could be quark matter not bound into hadrons. (A compact star composed entirely of strange matter would be called a strange star.) However so far observations have neither indicated nor ruled out such exotic states of matter.



History of Discovery

In 1932, Sir James Chadwick discovered the neutron as an elementary particle, for which he was awarded the Nobel Prize in Physics in 1935.

In 1933, Walter Baade and Fritz Zwicky proposed the existence of the neutron star, only a year after Chadwick's discovery of the neutron. In seeking an explanation for the origin of a supernova, they proposed that the neutron star is formed in a supernova. Supernovae are suddenly appearing dying stars in the sky, whose luminosity in the optical might outshine an entire galaxy for days to weeks. Baade and Zwicky correctly proposed at that time that the release of the gravitational binding energy of the neutron stars powers the supernova: "In the supernova process mass in bulk is annihilated". If the central part of a massive star before its collapse contains (for example) 3 solar masses, then a neutron star of 2 solar masses can be formed. The binding energy E of such a neutron star, when expressed in mass units via $E=mc^2$, is 1 solar mass. It is ultimately this energy that powers the supernova.

In 1967, Jocelyn Bell and Antony Hewish discovered radio pulses from a pulsar, later interpreted as originating from an isolated, rotating neutron star. The energy source is rotational energy of the neutron star. The largest number of known neutron stars are of this type (See Rotation-powered pulsar).

In 1971, Riccardo Giacconi, Herbert Gursky, Ed Kellogg, R. Levinson, E. Schreier, and H. Tananbaum discovered 4.8 second pulsations in an X-ray source in the constellation Centaurus, Cen X-3. They interpreted this as resulting from a rotating hot neutron star. The energy source is gravitational and results from a rain of gas falling onto the surface of the neutron star from a companion star or the interstellar medium (See Accretion-powered pulsar).

Types of Neutron Stars

- X-ray burster – a neutron star with a low mass binary companion from which matter is accreted resulting in irregular bursts of energy from the surface of the neutron star.
- Pulsar – general term for neutron stars that emit directed pulses of radiation towards us at regular intervals due to their strong magnetic fields.
- Magnetar – a neutron star with an extremely strong magnetic field; some magnetars are observed as soft gamma repeaters

Neutron stars rotate extremely rapidly after their creation due to the conservation of angular momentum; like an ice skater pulling in his or her arms, the slow rotation of the original star's core speeds up as it shrinks. A newborn neutron star can rotate several times a second; sometimes, when they orbit a companion star and are able to accrete matter from it, they can increase this to several thousand times per second, distorting into an oblate spheroid shape despite their own immense gravity (an equatorial bulge).

Over time, neutron stars slow down because their rotating magnetic fields radiate energy; older neutron stars may take several seconds for each revolution.
The rate at which a neutron star slows down its rotation is usually constant and very small: the observed rates are between 10-10 and 10-21 second for each rotation. In other words, for a typical slow down rate of 10-15 seconds per rotation, then a neutron star now rotating in 1 second will rotate in 1.000003 seconds after a century, or 1.03 seconds after 1 million years.

Sometimes a neutron star will spin up or undergo a glitch: a rapid and unexpected increase of its rotation speed (of the same, extremely small scale as the constant slowing down). Glitches are thought to be the effect of a sudden coupling between the superfluid interior and the solid crust.

Neutron stars also have very intense magnetic fields - typically about 1012 times stronger than Earth's. Neutron stars may "pulse" due to particle acceleration near the magnetic poles, which are not aligned with the rotation axis of the star. Through mechanisms not yet entirely understood, these particles produce coherent beams of radio emission. External viewers see these beams as pulses of radiation whenever the magnetic pole sweeps past the line of sight. The pulses come at the same rate as the rotation of the neutron star, and thus, appear periodic. Neutron stars which emit such pulses are called pulsars.

Pulsars

The first pulsar was discovered in 1967, by Jocelyn Bell Burnell and Antony Hewish of the University of Cambridge, UK. While using a radio array to study the scintillation of quasars, they found a very regular signal, consisting of pulses of radiation at a rate of one in every few seconds. Terrestrial origin of the signal was ruled out because the time it took the object to reappear was a sidereal day instead of a solar day. Initially baffled as to the unnaturally regular nature of its emissions, the pair dubbed their discovery LGM-1, for "little green men" (a comical name for intelligent beings of extraterrestrial origin). Their pulsar was later dubbed CP 1919, and is now known by a number of designators including PSR 1919+21. Although this choice of naming is indicative of the mystery surrounding the origin of the signals, according to Martin Rees,

the hypothesis that they were beacons from extraterrestrial civilizations were never taken very seriously. However, astrophysicist Peter A. Sturrock writes that "when the first regular radio signals from pulsars were discovered, the Cambridge scientists seriously considered that they might have come from an extraterrestrial civilization. They debated this possibility and decided that, if this proved to be correct, they could not make an announcement without checking with higher authorities. There was even some discussion about whether it might be in the best interests of mankind to destroy the evidence and forget it!" (Sturrock, 154)

CP 1919 emits in radio wavelengths, but pulsars have subsequently been found to emit in the X-ray and/or gamma ray wavelengths.

The word pulsar is a contraction of "pulsating star", and first appeared in print in 1968: "An entirely novel kind of star … came to light on Aug. 6 last year and … was referred to by astronomers as LGM (Little Green Men). Now … it is thought to be a novel type between a white dwarf and a neutron [sic]. The name Pulsar (Pulsating Star) is likely to be given to it. … Dr. A. Hewish … told me yesterday: '… I am sure that today every radio telescope is looking at the Pulsars.'"

The suggestion that pulsars were rotating neutron stars was put forth independently by Thomas Gold and Franco Pacini in 1968, and was soon proven beyond doubt by the discovery of a pulsar with a very short 33-millisecond pulse period in the Crab nebula.

In 1974, Antony Hewish was awarded the Nobel Prize in physics, the first astronomer to do so (astronomer Martin Ryle also received the prize in 1974 for his observations and inventions, in particular of the aperture synthesis technique). Considerable controversy is associated with the fact that Professor Hewish was awarded the prize while Bell, who made the initial discovery while she was a PhD student, was not.

Subsequent History

In 1974, Joseph Taylor and Russell Hulse discovered for the first time a pulsar in a binary system, PSR B1913+16. This pulsar orbits another neutron star with an orbital period of just eight hours. Einstein's theory of general relativity predicts that this system should emit strong gravitational radiation, causing the orbit to continually contract as it loses orbital energy. Observations of the pulsar soon confirmed this prediction, providing the first ever proof of the existence of gravitational waves. As of 2004, observations of this pulsar continue to agree with general relativity. In 1993 the Nobel prize in physics was awarded to Taylor and Hulse for the discovery of this pulsar.

In 1982, a pulsar with a rotation period of just 1.6 milliseconds was discovered, by Shri Kulkarni and Don Backer. Observations soon revealed that its magnetic field was much weaker than ordinary pulsars, while further discoveries cemented the idea that a new class of object, the "millisecond pulsars" (MSPs) had been found. MSPs are believed to be the end product of X-ray binaries. Owing to their extraordinarily rapid and stable rotation, MSPs can be used by astronomers as clocks rivalling the stability of the best atomic clocks on Earth. Factors affecting the arrival time of pulses at the Earth by more than a few hundred nanoseconds can be easily detected and used to make precise measurements. Physical parameters accessible through pulsar timing include the three-dimensional position of the pulsar, its proper motion, the electron content of the interstellar medium along the propagation path, the orbital parameters of any binary

companion, the pulsar rotation period and its evolution with time. Once these factors have been taken into account, deviations between the observed arrival times and predictions made using these parameters can be found and attributed to one of three possibilities: intrinsic variations in the spin period of the pulsar, errors in the realization of Terrestrial Time against which arrival times were measured, or the presence of background gravitational waves. Scientists are currently attempting to resolve these possibilities by comparing the deviations seen amongst several different pulsars, forming what is known as a Pulsar Timing Array. With luck, these efforts may lead to a time scale a factor of ten or more better than currently available, and the first ever direct detection of gravitational waves.

The first ever detected extrasolar planets were found orbiting a millisecond pulsar in 1990, by Aleksander Wolszczan. This discovery presented important evidence concerning the widespread existence of planets outside the solar system, although it is very unlikely that any life form could survive in the environment of intense radiation near a pulsar.

Pulsar classes

Three distinct classes of pulsars are currently known to astronomers, according to the source of energy that powers the radiation:

- Rotation-powered pulsars, where the loss of rotational energy of the star powers the radiation
- Accretion-powered pulsars (accounting for most but not all X-ray pulsars), where the gravitational potential energy of accreted matter is the energy source (producing X-rays that are observable from Earth), and
- Magnetars, where the decay of an extremely strong magnetic field powers the radiation.

Although all three classes of objects are neutron stars, their observable behavior and the underlying physics are quite different. There are, however, connections. For example, X-ray pulsars are probably old rotation-powered pulsars that have already lost most of their energy, and have only become visible again after their binary companions expanded and began transferring matter on to the neutron star. The process of accretion can in turn transfer enough angular momentum to the neutron star to "recycle" it as a rotation-powered millisecond pulsar.

Glitch prediction

In June 2006, astronomer John Middleditch and his team at LANL announced the first prediction of glitches with observational data from the Rossi X-ray Timing Explorer. They used observations of the pulsar PSR J0537-6910.

Application

The study of pulsars has resulted in many applications in physics and astronomy. Striking examples include the confirmation of the existence of gravitational radiation as predicted by general relativity and the first detection of an extra-solar planetary system.

Significant Pulsars

- The first radio pulsar, CP 1919 (now known as PSR 1919+21), with a pulse period of 1.337 seconds and a pulse width of 0.04 second, was discovered in 1967 (Nature 217:709-713, 1968). A drawing of this pulsar's radio waves was used as the cover of British rock band Joy Division's debut album, Unknown Pleasures.
- The first binary pulsar, PSR 1913+16, confirming general relativity and proving the existence of gravitational waves
- The first millisecond pulsar, PSR B1937+21
- The brightest millisecond pulsar, PSR J0437-4715
- The first X-ray pulsar, Cen X-3
- The first accreting millisecond X-ray pulsar, SAX J1808.4-3658
- The first pulsar with planets, PSR B1257+12
- The first double pulsar binary system, PSR J0737−3039
- The magnetar SGR 1806-20 produced the largest burst of energy in the Galaxy ever experimentally recorded on 27 December 2004
- PSR B1931+24 "... appears as a normal pulsar for about a week and then 'switches off' for about one month before emitting pulses again. [..] this pulsar slows down more rapidly when the pulsar is on than when it is off. [.. the] breaking mechanism must be related to the radio emission and the processes creating it and the additional slow-down can be explained by a wind of particles leaving the pulsar's magnetosphere and carrying away rotational energy
- PSR J1748-2446ad, at 716 Hz, the fastest spinning pulsar known

Magnetar

A magnetar is a neutron star with an extremely powerful magnetic field, the decay of which powers the emission of copious amounts of high-energy electromagnetic radiation, particularly X-rays and gamma-rays. The theory regarding these objects was formulated by Robert Duncan and Christopher Thompson in 1992. In the course of the decade that followed, the magnetar hypothesis has become widely accepted as a likely physical explanation for observable objects known as soft gamma repeaters and anomalous X-ray pulsars.

When, in a supernova, a star collapses to a neutron star, its magnetic field increases dramatically in strength (halving a linear dimension increases the magnetic field fourfold). Duncan and Thompson calculated that the magnetic field of a neutron star, normally an already enormous 108 teslas could, through the dynamo mechanism, grow even larger, to more than 1011 teslas (or 1015 gauss). Such a highly magnetic neutron star is called a magnetar.

The supernova might lose 10% of its mass in the explosion. In order for such large stars (10–30 solar masses) not to collapse straight into a black hole, they have to shed a larger proportion of their mass—maybe another 80%.

It is estimated that about 1 in 10 supernova explosions results in a magnetar rather than a more standard neutron star or pulsar. This happens when the star already has a fast rotation and strong magnetic field before the supernova. It is thought that a magnetar's magnetic field is created as a result of a convection-driven dynamo of hot nuclear matter in the neutron star's interior that operates in the first ten seconds or so of a neutron star's life. If the neutron star is initially rotating as fast as the period of convection, about ten milliseconds, then the convection currents are able to operate globally and transfer a

significant amount of their kinetic energy into magnetic field strength. In slower-rotating neutron stars, the convection currents form only in local regions.

In the outer layers of a magnetar, which consist of a plasma of heavy elements (mostly iron), tensions can arise that lead to 'starquakes'. These seismic vibrations are extremely energetic, and result in a burst of X-ray and gamma ray radiation. To astronomers, such an object is known as a soft gamma repeater.

The life of a magnetar as a soft gamma repeater is short: Starquakes cause large ejections of energy, and matter. The matter is held in the strong magnetic field, and evaporates in minutes. Radial ejection of matter carries away angular momentum which slows the rotation. Magnetars lose rotational speed at a higher rate than other neutron stars, attributed to their high magnetic field. Slowdown weakens the magnetic field, and after only about 10,000 years the starquakes cease. After this, the star still radiates X-rays, and astronomers conjecture it forms an anomalous X-ray pulsar. After another 10,000 years, it becomes completely quiet. Starquakes are explosive events and some have been directly recorded, such as that at SGR 1806-20 on December 27, 2004, and more are expected to be recorded as telescopes increase in number and capability.

A magnetic field above 10 gigateslas is strong enough to wipe a credit card from half the distance of the Moon from the Earth. A small neodymium based rare earth magnet has a field of about 1 tesla, Earth has a geomagnetic field of 30-60 microteslas, and most media used for data storage can be erased with a millitesla field at very short range.

The magnetic field of a magnetar would be lethal at a distance of up to 1000 km, tearing tissues due to the diamagnetism of water. Tidal forces of a 1.4 solar mass magnetar would also be lethal at such a distance, pulling an average-sized human apart with a force of over 20 kilonewtons (over 4500 pounds-force).

Known magnetars:

- SGR 1806-20, located 50,000 light-years from Earth on the far side of our Milky Way galaxy in the constellation of Sagittarius.
- 1E 1048.1-5937, located 9,000 light-years away in the constellation Carina. The original star, out of which the magnetar formed, had a mass 30 to 40 times that of the Sun.

Quark Star

A quark star or strange star is a hypothetical type of star composed of quark matter, or strange matter. These are ultra-dense phases of degenerate matter theorized to form inside particularly massive neutron stars.

It is theorized that when the neutron-degenerate matter which makes up a neutron star is put under sufficient pressure due to the star's gravity, the individual neutrons break down into their constituent quarks, up quarks and down quarks. Some of these quarks may then become strange quarks and form strange matter. The star then becomes known as a "quark star" or "strange star", similar to a single gigantic hadron (but bound by gravity rather than the color force). Quark matter/strange matter is one candidate for the theoretical dark matter that is a feature of several cosmological theories.

A quark star may be formed from a neutron star through a process called quark deconfinement. This process may produce a quark nova. The resultant star should have free quarks in its interior. The deconfinement process should release immense amounts of

energy, perhaps being the most energetic explosions in existence. It may be that gamma ray bursts are indeed quark-novae. A quark star lies between neutron stars and black holes in terms of both mass and density, and if sufficient additional matter is added to a quark star, it will collapse into a black hole.

Neutron stars with masses of 1.5 - 1.8 solar masses with rapid spin are theoretically the best candidates for conversion. This amounts to 1% of the projected neutron star population. An extrapolation based on this indicates that up to 2 quark-novae may occur in the observable universe each day.

Theoretically quark stars may be radio quiet, so radio-quiet neutron stars may be quark stars.

Preon Star

A preon star is a hypothetical compact star made of preons, a group of theoretical subatomic particles that may compose quarks and leptons. Preon stars would be expected to have huge densities, exceeding 1020 g/cm³ — intermediate between neutron stars and black holes. A preon star having the same mass as Earth would be about five meters in diameter.

Such objects could be detected in principle through gravitational lensing of gamma rays. The presence of preon stars could potentially explain the puzzling observations that lead to the dark matter hypothesis.

Preon stars could originate from supernova explosions or the big bang, although it seems difficult to explain how such light and compact objects could be formed.

Brown Dwarf

Brown dwarfs are sub-stellar objects with a mass below that necessary to maintain hydrogen-burning nuclear fusion reactions in their cores, as do stars on the main sequence, but which have fully convective surfaces and interiors, with no chemical differentiation by depth. Brown dwarfs occupy the mass range between that of large gas-giant planets and the lowest mass stars (anywhere between 75 and 80 Jupiter masses). Currently there is a large ambiguity as to what separates a brown dwarf from a giant planet at very low brown dwarf masses (~13 Jupiter masses). There is some question as to whether brown dwarfs are required to have experienced fusion at some point in their history; in any event, brown dwarfs heavier than 13 Jupiter masses (M_J) do fuse deuterium and above roughly 65 M_J fuse both deuterium and lithium. Currently, the only planet known to orbit a brown dwarf star is 2M1207b.

Brown dwarfs, a term coined by Jill Tarter in 1975, were originally called black dwarfs, a classification for dark substellar objects floating freely in space which were too low in mass to sustain stable hydrogen fusion (the term black dwarf currently refers to a white dwarf that has cooled down so that it no longer emits heat or light). Alternative names have been proposed, including Planetar and Substar.

Early theories concerning the nature of the lowest mass stars and the hydrogen burning limit suggested that objects with a mass less than 0.07 solar masses for Population I objects or objects with a mass less than 0.09 solar masses for Population II objects would never go through normal stellar evolution and would become a completely degenerate star (Kumar 1963). The role of deuterium-burning down to 0.012 solar masses and the impact of dust formation in the cool outer atmospheres of brown dwarfs was

understood by the late eighties. They would however be hard to find in the sky, as they would emit almost no light. Their strongest emissions would be in the infrared (IR) spectrum, and ground-based IR detectors were too imprecise for a few decades after that to firmly identify any brown dwarfs.

Since those earlier times, numerous searches involving various methods have been conducted to find these objects. Some of those methods included multi-color imaging surveys around field stars, imaging surveys for faint companions to main sequence dwarfs and white dwarfs, surveys of young star clusters and radial velocity monitoring for close companions.

For many years, efforts to discover brown dwarfs were frustrating and searches to find them seemed fruitless. In 1988, however, University of California at Los Angeles professors Eric Becklin and Ben Zuckerman identified a faint companion to GD 165 in an infrared search of white dwarfs. The spectrum of GD 165B was very red and enigmatic, showing none of the features expected of a low-mass red dwarf star. It became clear that GD 165B would need to be classified as a much cooler object than the latest M dwarfs known at that time. GD 165B remained unique for almost a decade until the advent of the Two Micron All Sky Survey (2MASS) when Davy Kirkpatrick, out of the California Institute of Technology, and others discovered many objects with similar colors and spectral features.

Today, GD 165B is recognized as the prototype of a class of objects now called "L dwarfs". While the discovery of the coolest dwarf was highly significant at the time it was debated whether GD 165B would be classified as a brown dwarf or simply a very low mass star since observationally it is very difficult to distinguish between the two. Interestingly, soon after the discovery of GD 165B other brown dwarf candidates were reported. Most failed to live up to their candidacy however, and with further checks for substellar nature, such as the lithium test, many turned out to be stellar objects and not true brown dwarfs. When young (up to a gigayear old), brown dwarfs can have temperatures and luminosities similar to some stars, so other distinguishing characteristics are necessary, such as the presence of lithium. Stars will burn lithium in a little over 100 Myr, at most, while most brown dwarfs will never acquire high enough core temperatures to do so. Thus, the detection of lithium in the atmosphere of a candidate object ensures its status as a brown dwarf.

In 1995 the study of brown dwarfs changed dramatically with the discovery of three incontrovertible substellar objects, some of which were identified by the presence of the 6708 Li line. The most notable of these objects was Gliese 229B which was found to have a temperature and luminosity well below the stellar range. Remarkably, its near-infrared spectrum clearly exhibited a methane absorption band at 2 micrometers, a feature that had previously only been observed in gas giant atmospheres and the atmosphere of Saturn's moon, Titan. Methane absorption is not expected at the temperatures of main-sequence stars. This discovery helped to establish yet another spectral class even cooler than L dwarfs known as "T dwarfs" for which Gl 229B is the prototype.

Since 1995, when the first brown dwarf was confirmed, hundreds have been identified. Brown dwarfs close to Earth include Epsilon Indi Ba and Bb, a pair of dwarfs around 12 light-years from the Sun.

Theory

The standard mechanism for star birth is through the gravitational collapse of a cold interstellar cloud of gas and dust. As the cloud contracts it heats up. The release of gravitational potential energy is the source of this heat. Early in the process the contracting gas quickly radiates away much of the energy, allowing the collapse to continue. Eventually, the central region becomes sufficiently dense to trap radiation. Consequently, the central temperature and density of the collapsed cloud increases dramatically with time, slowing the contraction, until the conditions are hot and dense enough for thermonuclear reactions to occur in the core of the protostar. For most stars, gas and radiation pressure generated by the thermonuclear fusion reactions within the core of the star will support it against any further gravitational contraction. Hydrostatic equilibrium is reached and the star will spend most of its lifetime burning hydrogen to helium as a main-sequence star.

If, however, the mass of the protostar is less than about 0.08 solar mass, normal hydrogen thermonuclear fusion reactions will not ignite in the core. Gravitational contraction does not heat the small protostar very effectively, and before the temperature in the core can increase enough to trigger fusion, the density reaches the point where electrons become closely packed enough to create quantum electron degeneracy pressure. According to the brown dwarf interior models, typical conditions in the core for density, temperature and pressure are expected to be the following:

$$\rho_c \sim 10 - 10^3 g/cm^3$$
$$T_c \lesssim 3 \times 10^6 K$$
$$P_c \sim 10^5 Mbar$$

Further gravitational contraction is prevented and the result is a "failed star", or brown dwarf that simply cools off by radiating away its internal thermal energy.

Distinguishing high mass brown dwarfs from low mass stars

1) Lithium: Lithium is generally present in brown dwarfs and not in low-mass stars. Stars, which achieve the high temperature necessary for fusing hydrogen, rapidly deplete their lithium. This occurs by a collision of Lithium-7 and a proton producing two Helium-4 nuclei. The temperature necessary for this reaction is just below the temperature necessary for hydrogen fusion. Convection in low-mass stars ensures that lithium in the whole volume of the star is depleted. Therefore, the presence of the lithium line in a candidate brown dwarf's spectrum is a strong indicator that it is indeed substellar. The use of lithium to distinguish candidate brown dwarfs from low-mass stars is commonly referred to as the lithium test, and was pioneered by Rafael Rebolo and colleagues.

However, lithium is also seen in very young stars, which have not yet had a chance to burn it off. Heavier stars like our sun can retain lithium in their outer atmospheres, which never get hot enough for lithium depletion, but those are distinguishable from brown dwarfs by their size.

Contrariwise, brown dwarfs at the high end of their mass range can be hot enough to deplete their lithium when they are young. Dwarfs of mass greater than 65 MJ can burn off their lithium by the time they are half a billion years old [Kulkarni], thus this test is not perfect.

2) Methane: Unlike stars, older brown dwarfs are sometimes cool enough that over very long periods of time their atmospheres can gather observable quantities of methane. Dwarfs confirmed in this fashion include Gliese 229B.

3) Luminosity: Main sequence stars cool, but eventually reach a minimum luminosity which they can sustain through steady fusion. This varies from star to star, but is generally at least 0.01% the luminosity of our Sun. Brown dwarfs cool and darken steadily over their lifetimes: sufficiently old dwarfs will be too faint to be a star.

Distinguishing low mass brown dwarfs from high mass planets

A remarkable property of brown dwarfs is that they are all roughly the same radius, more or less the radius of Jupiter. At the high end of their mass range (60-90 Jupiter masses), the volume of a brown dwarf is governed primarily by electron degeneracy pressure, as it is in white dwarfs; at the low end of the range (1-10 Jupiter masses), their volume is governed primarily by Coulomb pressure, as it is in planets. The net result is that the radii of brown dwarfs vary by only 10-15% over the range of possible masses. This can make distinguishing them from planets difficult.

In addition, many brown dwarfs undergo no fusion; those at the low end of the mass range (under 13 Jupiter masses) are never hot enough to fuse even deuterium, and even those at the high end of the mass range (over 60 Jupiter masses) cool quickly enough that they no longer undergo fusion after something on the order of 10 million years. However, there are other ways to distinguish dwarfs from planets:

1) Density is a clear giveaway. Brown dwarfs are all about the same radius; so anything that size with over 10 Jupiter masses is unlikely to be a planet.

2) X-ray and infrared spectra are telltale signs. Some brown dwarfs emit X-rays; and all "warm" dwarfs continue to glow tellingly in the red and infrared spectra until they cool to planet like temperatures (under 1000 K).

Some astronomers believe that there is in fact no actual black-and-white line separating light brown dwarfs from heavy planets, and that rather there is a continuum. For example, Jupiter and Saturn are both made out of primarily hydrogen and helium, like the Sun. Saturn is nearly as large as Jupiter, despite having only 30% the mass. Three of the giants in our solar system (Jupiter, Saturn, and Neptune) emit more heat than they receive from the Sun. And all four giant planets have their own "planetary systems" -- their moons. In addition, it has been found that both planets and brown dwarfs can have eccentric orbits. Currently, the International Astronomical Union considers objects with masses above the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity) to be a brown dwarf, whereas those objects under that mass (and orbiting stars or stellar remnants) are considered planets.

Classification of brown dwarfs

The defining characteristic of spectral class M, the coolest type in the long-standing classical stellar sequence, is an optical spectrum dominated by absorption bands of titanium oxide (TiO) and vanadium oxide (VO) molecules. However, GD 165B, the cool companion to the white dwarf GD 165 had none of the hallmark TiO features of M dwarfs. The subsequent identification of many field counterparts to GD 165B ultimately led Kirkpatrick and others to the definition of a new spectral class, the L dwarfs, defined

in the red optical region by weakening metal-oxide bands (TiO, VO) but strong metal hydride bands (FeH, CrH, MgH, CaH) and prominent alkali lines (Na I, K I, Cs I, Rb I). As of April 2005, over 400 L dwarfs have been identified (see link in references section below), most by wide-field surveys: the Two Micron All Sky Survey (2MASS), the Deep Near Infrared Survey of the Southern Sky (DENIS), and the Sloan Digital Sky Survey (SDSS).

As GD 165B is the prototype of the L dwarfs, Gliese 229B is the prototype of a second new spectral class, the T dwarfs. Whereas near-infrared (NIR) spectra of L dwarfs show strong absorption bands of H2O and carbon monoxide (CO), the NIR spectrum of Gliese 229B is dominated by absorption bands from methane (CH4), features that were only found in the giant planets of the solar system and Titan. CH4, H2O, and molecular hydrogen (H2) collision-induced absorption (CIA) give Gliese 229B blue near-infrared colors. Its steeply sloped red optical spectrum also lacks the FeH and CrH bands that characterize L dwarfs and instead is influenced by exceptionally broad absorption features from the alkali metals Na and K. These differences led Kirkpatrick to propose the T spectral class for objects exhibiting H- and K-band CH4 absorption. As of April 2005, 58 T dwarfs are now known. NIR classification schemes for T dwarfs have recently been developed by Adam Burgasser and Tom Geballe. Theory suggests that L dwarfs are a mixture of very low-mass stars and sub-stellar objects (brown dwarfs), whereas the T dwarf class is composed entirely of brown dwarfs.

The majority of flux emitted by L and T dwarfs is in the 1 to 2.5 micrometer near-infrared range. Low and decreasing temperatures through the late M, L, and T dwarf sequence result in a rich near-infrared spectrum containing a wide variety of features, from relatively narrow lines of neutral atomic species to broad molecular bands, all of which have different dependencies on temperature, gravity, and metallicity. Furthermore, these low temperature conditions favor condensation out of the gas state and the formation of grains.

Typical atmospheres of known brown dwarfs range in temperature from 2200 down to 750 K (Burrows et al. 2001). Compared to stars, which warm themselves with steady internal fusion, brown dwarfs cool quickly over time; more massive dwarfs cool more slowly than less massive ones.

Red Dwarf

According to the Hertzsprung-Russell diagram, a red dwarf star is a small and relatively cool star, of the main sequence, either late K or M spectral type. They constitute the vast majority of stars and have a mass of less than one-half that of the Sun (down to about 0.075 solar masses, which are brown dwarfs) and a surface temperature of less than 3,500 K. Red dwarfs fuse hydrogen to helium via the proton-proton (PP) chain. Due to the low temperatures in the core, fusion proceeds slowly. Thus red dwarfs have an enormous estimated lifespan; from tens of billions up to trillions of years depending upon mass. Consequently they emit little light, sometimes as little as 1/10,000th that of the sun. In general red dwarfs transport energy from the core to the surface via convection. As red dwarfs are fully convective, all the hydrogen in the star is available for fusion, which further increases their lifespan. Red dwarfs never initiate helium fusion via the triple alpha process and so cannot evolve beyond the red giant phase. In any event, there has

not been sufficient time since the Big Bang for red dwarfs to evolve off the main sequence.

The fact that red dwarfs and other low mass stars remain on the main sequence while more massive stars have moved off the main sequence allows one to date star clusters by finding the mass at which the stars turn off the main sequence. This provides a lower, stellar, age limit to the Universe and also allows formation timescales to be placed upon the structures within the Milky Way galaxy. Namely the Galactic halo and Galactic disk.

One mystery which has not been solved as of 2007 is the lack of red dwarf stars with no metals (in astronomy a metal is any element other than hydrogen and helium). The Big Bang model predicts the first generation of stars should have only hydrogen, helium, and lithium. If such stars included red dwarfs, they should still be observable today, but as yet none have been identified. One explanation is that without heavy elements, low mass stars cannot form. Alternatively as they are dim and could be few in number, we simply may not have observed them yet.

Red dwarfs are the most common star type in the Galaxy, at least in the neighborhood of the Sun. Proxima Centauri, the nearest star to the Sun, is a red dwarf (Type M5, magnitude 11.0), as are twenty of the next thirty nearest. However, due to their low luminosity, individual red dwarfs cannot easily be observed over the vast intergalactic distances that luminous stars can.

Exoplanets have been discovered orbiting red dwarfs in 2005, one as small as the size of Neptune, or seventeen earth masses. It orbits just 6 million kilometers (0.04 AU) from its star, and so is estimated to have a surface temperature of 150 °C, despite how dim the star is. In 2006 a planet similar in size to Earth was found orbiting a red dwarf; it lies 390 million km (2.6 AU) from the star and its surface temperature is -220 °C (56 K).

Flare Star

A flare star is a variable star which can undergo unpredictable dramatic increases in brightness for a few minutes or a few hours. The brightness increase is across the spectrum, from X rays to radio waves.

Flare stars are dim red dwarfs, although recent research indicates that brown dwarfs might also be capable of flaring.

The first known flare stars (V1396 Cygni and AT Microscopii) were discovered in 1924. However, the best-known flare star (UV Ceti) was discovered in 1948, and today flare stars are sometimes known as UV Ceti variables.

The Sun's nearest stellar neighbor Proxima Centauri is a flare star, as is another near neighbor Wolf 359. Barnard's Star, the second nearest star system, is also suspected of being a flare star. Because they are so intrinsically faint, all known flare stars are within about 60 light years from Earth.

It is believed that the flares on flare stars are analogous to solar flares.

Orange Dwarf

Orange dwarfs are main sequence stars of spectral type K. These stars are intermediate in size between M class red dwarf stars and yellow G class stars such as the Earth's Sun. Orange dwarfs vary from 0.5 to 0.9 times the mass of the Sun and have a

surface temperature between 4000 and 5200 degrees Celsius. Examples include Alpha Centauri B and Epsilon Indi.

These stars are of particular interest in the search for extraterrestrial life because they are stable on the main sequence for a very long time (15 to 30 billion years, compared to 10 billion for the Earth's Sun). This may create an opportunity for life to evolve on terrestrial planets orbiting such stars.

Yellow Dwarf

In astronomy, a yellow dwarf is a small (about 0.9 to 1.4 solar masses), yellow main sequence star that is in the process of converting hydrogen to helium in its core by means of nuclear fusion.

Our Sun is the most well-known example of a yellow dwarf.

A yellow dwarf's lifespan is about 10 billion years, until its supply of hydrogen runs out. When this happens, the star expands to many times its previous size and becomes a red giant. The star Aldebaran is an example of a red giant. Eventually the red giant sheds its outer layers of gas, which become a planetary nebula, while the core collapses into a small, dense white dwarf.

Blue Dwarf

Blue dwarfs are main sequence stars of spectral type O.

A typical type O dwarf has a mass of 50 Suns and is tens of thousands of times more luminous than the Sun. Hottest of all the main sequence stars yet known are of type O3. Because very massive stars have short lifespans, blue dwarfs are extremely rare: only about one star in ten million is a blue dwarf. However, because they are so luminous (and thus more easily seen), a disproportionate number of O stars have been charted in comparison to other star classes.

Runaway Star

A runaway star is one which is moving through space with an abnormally high velocity compared to other stars around it.

Two possible mechanisms may give rise to a runaway star. In the first scenario, a close encounter between two binary systems may result in the disruption of both systems, with some of the stars being ejected at high velocities. In the second scenario, a supernova explosion in a multiple star system can result in the remaining components moving away at high speed. While both mechanisms are theoretically possible, astronomers generally favor the supernova hypothesis as more likely in practice.

One example of a related set of runaway stars is the case of AE Aurigae, 53 Arietis and Mu Columbae, all of which are moving away from each other at velocities of over 100km/s (for comparison, the Sun moves through the galaxy at about 20km/s faster than the local average). Tracing their motions back, their paths intersect near to the Orion Nebula about 2 million years ago.

Cataclysmic Variable Star

Cataclysmic variables (also U Geminorum Stars) are a class of binary stars containing a white dwarf and a companion star. The companion star is usually a red

dwarf, although in some cases it is another white dwarf or a slightly evolved star (subgiant). Several hundred cataclysmic variables are known.

From the observational viewpoint, cataclysmic variables are relatively easy to discover. They are usually quite blue objects, whereas the majority of stars are red. The variability of these systems is usually quite rapid and strong. Strong ultraviolet or even X-ray emission and peculiar emission lines are other typical properties.

The stars are so close to each other that the gravity of the white dwarf distorts the secondary, and the white dwarf accretes matter from the companion. Therefore, the secondary is often referred to as the donor star. The infalling matter forms in most cases an accretion disc around the white dwarf. Strong UV and X-ray emission is often seen from the accretion disc. The accretion disk may be prone to an instability leading to dwarf nova outbursts, when a tenth of the disk material falls onto the white dwarf.

During the accretion process, mass is accumulating on the white dwarf surface. Usually the donor star is rich in hydrogen. Eventually the density and temperature at the bottom of the accumulated hydrogen layer rise high enough to ignite nuclear fusion reactions. The reactions burn the bulk of the hydrogen layer to helium in a short time. This is seen as a nova outburst. The outer parts of the hydrogen layer and some of the fusion products are ejected to interstellar space. If the accretion process continues long enough to bring the white dwarf close to the Chandrasekhar limit, the increasing interior density can ignite runaway carbon fusion and trigger a Type Ia supernova explosion, which completely disrupts the white dwarf.

Cataclysmic variables are subdivided into several smaller groups, often presented by a bright prototype star characteristic of the class. The prototype stars include SS Cygni, U Geminorum, Z Camelopardalis, SU Ursae Majoris, AM Herculis, DQ Herculis, VY Sculptoris, SW Sextantis.

In some cases the magnetic field of the white dwarf disrupts the inner accretion disk or even prevents disk formation. Magnetic systems often show strong and variable polarization in their optical light, and are therefore sometimes called intermediate polars (in case of a disrupted disk) or polars (in case of prevented disk formation). Another naming convention, often used in variable star classification, is naming the class after a well-known prototype star. Intermediate polars and polars are sometimes referred to as DQ Herculis stars and AM Herculis stars, respectively.

Black Hole

A black hole is an object predicted by general relativity, with a gravitational field so powerful that even electromagnetic radiation (such as light) cannot escape its pull.

A black hole is defined to be a region of space-time where escape to the outside universe is impossible. The outer boundary of this region is called the event horizon. Nothing can move from inside the event horizon to the outside, even briefly, due to the extreme gravitational field existing within the region. For the same reason, observers outside the event horizon cannot see any events which may be happening within the event horizon; thus any energy being radiated or events happening within the region are forever unable to be seen or detected from outside. Within the black hole is a singularity, an anomalous place where matter is compressed to the degree that the known laws of physics no longer apply to it.

Theoretically, a black hole can be any size. Astrophysicists expect to find black holes with masses ranging between roughly the mass of the Sun ("stellar-mass" black holes) to many millions of times the mass of the Sun (supermassive black holes).

The existence of black holes in the universe is well supported by astronomical observation, particularly from studying X-ray emission from X-ray binaries and active galactic nuclei. It has also been hypothesized that black holes radiate an undetectably small amount of energy due to quantum mechanical effects. This is called Hawking radiation.

Simple Overview

Most planets and other celestial bodies are stable because the Pauli force between electrons prevents atoms from collapsing into each other, while gravity, electromagnetism, and the strong force pull them together. These create a balance which allows material bodies to retain their shape and structure. In extreme circumstances, however, if there is enough matter in a small enough space, gravity ends up winning, and the matter collapses: electrons cannot stay distant from the atomic nucleus, and incredibly dense matter forms (sometimes called neutronium). Eventually, if the star is massive enough, even the Pauli force between nucleons cannot resist gravity and the star collapses into itself further forming a black hole. In a way that can be hard to imagine, nothing can stop this collapse if enough matter gets into a small enough space, and the matter collapses to a point of zero height, width, and depth, known as a singularity, in which the matter is so dense it is no longer "matter" in any real sense, but some kind of anomaly in space. Anything that gets too close to this singularity will also collapse into it the same way, whether it is matter, energy or even light itself, which is the fastest thing in the universe. The failure of even light to escape its gravitation is how the phenomenon initially acquired the name black hole.

Because matter and energy which passes this "boundary" can never escape back again, observers outside this invisible "boundary" can neither see inside nor detect what might happen within the interior - it is forever unable to be witnessed. The invisible 'dividing line' in space where matter or energy will be unavoidably drawn into the black hole is known as the event horizon, because like the earth's horizon nothing can be seen beyond it.

It was later found that energy can escape from black holes in an unexpected way, and that therefore black holes can evaporate. In space, virtual particles are continually coming into existence and vanishing on a microscopic scale that is so small they cannot easily be detected. This is a consequence of quantum physics and only works on a subatomic scale. Conceptually, these particles can be imagined to appear in pairs and vanish a tiny fraction of a second later again. For this reason they are not readily noticed. But close to the black hole's event horizon, the intense gravitational field separates the two particles even in the fractional second that they exist. One particle may be absorbed into the black hole, the other escapes. From an external perspective all that is seen is the second of these, giving the appearance of energy being radiated outward, escaping from its gravitational field beyond the event horizon. In this way, paradoxically, black holes can evaporate. This process is thought to be significant for the very smallest black holes, as a black hole of stellar mass or larger would absorb more energy from cosmic microwave background radiation than they lose this way. The radiation emitted is referred to as Hawking radiation.

Black holes generally come in two types: those with a mass up to ten times the mass of our Sun, and those with a mass that is millions or billions of times that of our sun. The latter are called supermassive black holes, and are thought to exist at the centers of galaxies. Micro black holes are believed to be possible but very short-lived, capable of creation under extreme circumstances such as the Big Bang or perhaps by very high powered particle accelerators or ultra-high-energy cosmic rays.

Formation and size

General relativity (as well as most other metric theories of gravity) not only says that black holes can exist, but in fact predicts that they will be formed in nature whenever a sufficient amount of mass gets packed in a given region of space, through a process called gravitational collapse; as the mass inside the given region of space increases, its gravity becomes stronger and (in the language of relativity) increasingly deforms the space around it, ultimately until nothing (not even light) can escape the gravity; at this point an event horizon is formed, and matter and energy must inevitably collapse to a density beyond the limits of known physics. For example, if the Sun was compressed to a radius of roughly three kilometers (about 1/232,000 its present size), the resulting gravitational field would create an event horizon around it, and thus a black hole.

A quantitative analysis of this idea led to the prediction that a stellar remnant above about three to five times the mass of the Sun (the Tolman-Oppenheimer-Volkoff limit) would be unable to support itself as a neutron star via degeneracy pressure, and would inevitably collapse into a black hole. Stellar remnants with this mass are expected to be produced immediately at the end of the lives of stars that are more than 25 to 50 times the mass of the Sun, or by accretion of matter onto an existing neutron star.

Stellar collapse will generate black holes containing at least three solar masses. Black holes smaller than this limit can only be created if their matter is subjected to sufficient pressure from some source other than self-gravitation. The enormous pressures needed for this are thought to have existed in the very early stages of the universe, possibly creating primordial black holes which could have masses smaller than that of the Sun.

Supermassive black holes are believed to exist in the center of most galaxies, including our own Milky Way. This type of black hole contains millions to billions of solar masses, and there are several models of how they might have been formed. The first is via gravitational collapse of a dense cluster of stars. A second is by large amounts of mass accreting onto a "seed" black hole of stellar mass. A third is by repeated fusion of smaller black holes. Effects of such supermassive black holes on spacetime may be observed in regions as the Virgo cluster of galaxies, for example, the location of M87 (see image below) and its neighbors.

Intermediate-mass black holes have a mass between that of stellar and supermassive black holes, typically in the range of thousands of solar masses. Intermediate-mass black holes have been proposed as a possible power source for ultra-luminous X ray sources, and in 2004 detection was claimed of an intermediate-mass black hole orbiting the Sagittarius A supermassive black hole candidate at the core of the Milky Way galaxy. This detection is disputed.

The lower limit on the mass of a black hole comes from the quantum arguments. According to the most commonly accepted physics, one should not expect to observe black holes lighter than the Planck mass, or approximately 10-5 g, and even those would

only exist for minuscule periods of time before evaporating. If true, this limit would rule out the possibility of creating miniature black holes in the laboratory in the foreseeable future: even today, center-of-mass collision energies of the world's most advanced particle accelerators are still 14-15 orders of magnitude lower than the Planck mass.

However, certain models of unification of the four fundamental forces do allow the formation of micro black holes under laboratory conditions. These postulate that the energy at which gravity is unified with the other forces is comparable to the energy at which the other three are unified, as opposed to being the Planck energy (which is much higher). This would allow production of extremely short-lived black holes in terrestrial particle accelerators. No conclusive evidence of this type of black hole production has been presented, though even a negative result improves constraints on compactification of extra dimensions from string theory or other models of physics

Observation

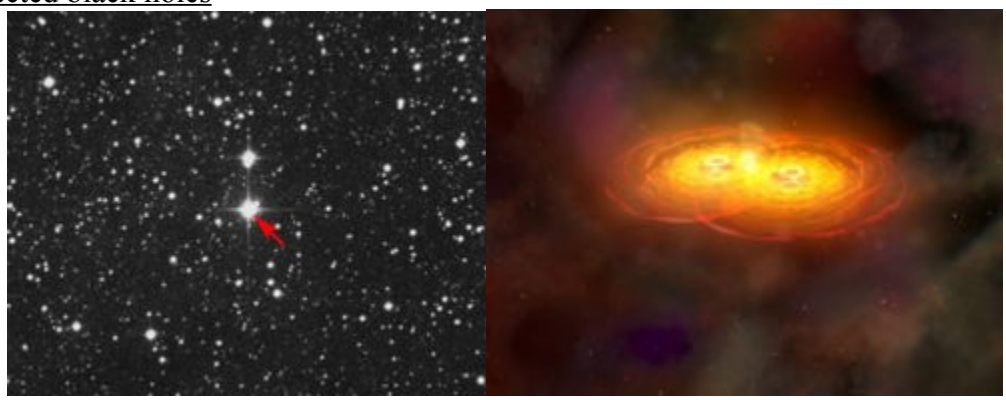
In theory, no object within the event horizon of a black hole can ever escape, including light. However, black holes can be inductively detected from observation of phenomena near them, such as gravitational lensing, galactic jets, and stars that appear to be in orbit (typically with short orbital periods of only a few hours or days suggesting a massive partner) around a point in space where there is no visible matter.

The most conspicuous effects are believed to come from matter accreting onto a black hole, which is predicted to collect into an extremely hot and fast-spinning accretion disk. The internal viscosity of the disk causes it to become extremely hot, and emit large amounts of X-ray and ultraviolet radiation. This process is extremely efficient and can convert about 10% of the rest mass energy of an object into radiation, as opposed to nuclear fusion which can only convert a few percent of the mass to energy. Other observed effects are narrow jets of particles at relativistic speeds heading along the disk's axis.

However, accretion disks, jets, and orbiting objects are found not only around black holes, but also around other objects such as neutron stars and white dwarfs; and the dynamics of bodies near these non-black hole attractors is largely similar to that of bodies around black holes. It is currently a very complex and active field of research involving magnetic fields and plasma physics to disentangle what is going on. Hence, for the most part, observations of accretion disks and orbital motions merely indicate that there is a compact object of a certain mass, and says very little about the nature of that object. The identification of an object as a black hole requires the further assumption that no other object (or bound system of objects) could be so massive and compact. Most astrophysicists accept that this is the case, since according to general relativity, any concentration of matter of sufficient density must necessarily collapse into a black hole.

One important observable difference between black holes and other compact massive objects is that any infalling matter will eventually collide with the latter at relativistic speeds, leading to emission as the kinetic energy of the matter is thermalized. In addition thermonuclear "burning" may occur on the surface of compact massive objects as material collides or builds up. These processes produce irregular intense flares of X-rays and other hard radiation around some objects. The lack of such flare-ups around such a compact concentration of mass is taken as evidence suggesting that the object is a black hole which lacks a surface onto which matter can collect and from which radiation can be emitted.

Suspected black holes



Location of the X-ray source Cygnus X-1 which is widely accepted to be a 10 solar mass black hole orbiting a blue giant star (left) and an artist depiction of two black holes merging (right)

There is now a great deal of indirect astronomical observational evidence for black holes in two mass ranges:

- stellar mass black holes with masses of a typical star (4 – 15 times the mass of our Sun), and
- supermassive black holes with masses ranging from on the order of 105 to 1010 solar masses/

Additionally, there is some evidence for intermediate-mass black holes (IMBHs), those with masses of a few hundred to a few thousand times that of the Sun. These black holes may be responsible for the emission from ultraluminous X-ray sources (ULXs). Candidates for stellar-mass black holes were identified mainly by the presence of accretion disks of the right size and speed, without the irregular flare-ups that are expected from disks around other compact objects. Stellar-mass black holes may be involved in gamma ray bursts (GRBs); short duration GRBs are believed to be caused by colliding neutron stars, which form a black hole on merging. Observations of long GRBs in association with supernovae suggest that long GRBs are caused by collapsars; a massive star whose core collapses to form a black hole, drawing in the surrounding material. Therefore, a GRB could possibly signal the birth of a new black hole, aiding efforts to search for them.

Candidates for more massive black holes were first provided by the active galactic nuclei and quasars, discovered by radioastronomers in the 1960s. The efficient conversion of mass into energy by friction in the accretion disk of a black hole seems to be the only explanation for the copious amounts of energy generated by such objects. Indeed the introduction of this theory in the 1970s removed a major objection to the belief that quasars were distant galaxies — namely, that no physical mechanism could generate that much energy.

From observations in the 1980s of motions of stars around the galactic centre, it is now believed that such supermassive black holes exist in the centre of most galaxies, including our own Milky Way. Sagittarius A* is now generally agreed to be the location of a supermassive black hole at the centre of the Milky Way galaxy. The orbits of stars

within a few AU of Sagittarius A* rule out any object other than a black hole at the centre of the Milky Way assuming the current standard laws of physics are correct.

The jet emitted by the galaxy M87 in this image is thought to be caused by a supermassive black hole at the galaxy's centre

The current picture is that all galaxies may have a supermassive black hole in their centre, and that this black hole accretes gas and dust in the middle of the galaxies generating huge amounts of radiation — until all the nearby mass has been swallowed and the process shuts off. This picture may also explain why there are no nearby quasars.

Although the details are still not clear, it seems that the growth of the black hole is intimately related to the growth of the spheroidal component — an elliptical galaxy, or the bulge of a spiral galaxy - in which it lives.

In 2002, the Hubble Telescope identified evidence indicating that intermediate size black holes exist in globular clusters named M15 and G1. The evidence for the black holes stemmed from the orbital velocity of the stars in the globular clusters; however, a group of neutron stars could cause similar observations.

Nearest black hole candidates

Apart from Sagittarius A*, the black hole in our Milky Way's center, there are several strong black hole candidates nearer than it to us, all of them X-ray binaries which draw matter from their partner via an accretion disk. They have masses from three to more than a dozen sun masses.

Name	Mass in M☉	Mass of partner (M☉)	Orbital period (days)	Distance from Earth (light years)
A0620-00	9−13	2.6−2.8	0.33	~3500
GRO J1655-40	6−6.5	2,6−2,8	2.8	5000−10000
XTE J1118+480	6.4−7.2	6−6.5	0.17	6200
Cyg X-1	7−13	0.25	5.6	6000−8000
GRO J0422+32	3−5	1.1	0.21	~8500

GS 2000+25	7−8	4.9−5.1	0.35	~8800
V404 Cyg	10−14	6.0	6.5	~10000
GX 339-4		5−6	1.75	~15000
GRS 1124-683	6.5−8.2		0.43	~17000
XTE J1550-564	10−11	6.0−7.5	1.5	~17000
XTE J1819-254	10−18	~3	2.8	< 25000
4U 1543-475	8−10	0.25	1.1	~24000
Sgr A*	3.7 Million	–	–	~25000

Recent discoveries

In 2004, astronomers found 31 candidate supermassive black holes from searching obscured quasars. The lead scientist said that there are from two to five times as many supermassive black holes as previously predicted.

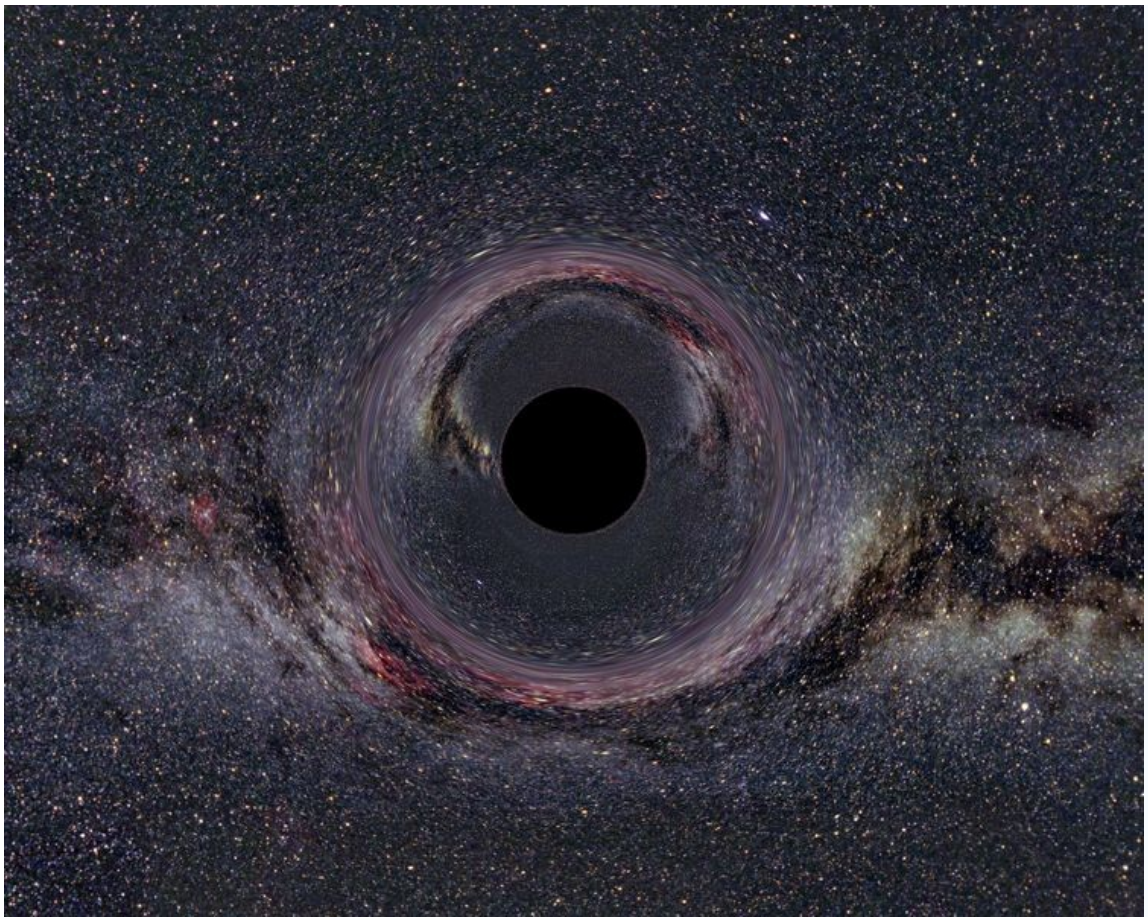
In June 2004 astronomers found a super-massive black hole, Q0906+6930, at the centre of a distant galaxy about 12.7 billion light years away. This observation indicated rapid creation of super-massive black holes in the early universe.

In November 2004 a team of astronomers reported the discovery of the first intermediate-mass black hole in our Galaxy, orbiting three light-years from Sagittarius A*. This medium black hole of 1,300 solar masses is within a cluster of seven stars, possibly the remnant of a massive star cluster that has been stripped down by the Galactic Centre. This observation may add support to the idea that supermassive black holes grow by absorbing nearby smaller black holes and stars.

In February 2005, a blue giant star SDSS J090745.0+24507 was found to be leaving the Milky Way at twice the escape velocity (0.0022 of the speed of light), having been catapulted out of the galactic core which its path can be traced back to. The high velocity of this star supports the hypothesis of a super-massive black hole in the centre of the galaxy.

The formation of micro black holes on Earth in particle accelerators has been tentatively reported, but not yet confirmed. So far there are no observed candidates for primordial black holes.

In January 2007, researchers at the University of Southampton in the United Kingdom reported finding a black hole inside a compact group of ancient stars known as a globular cluster. Many doubted newly-formed black holes could exist in such locations due to gravitational interactions.



A (simulated) Black Hole of ten solar masses as seen from a distance of 600 km with the Milky Way in the background (horizontal camera opening angle: 90°). The blurred ring is due to objects whose light must travel close enough to the black hole to suffer gravitational lensing distortion before being observed.

Features and theories

Black holes require the general relativistic concept of a curved spacetime: their most striking properties rely on a distortion of the geometry of the space surrounding them.

Gravitational field

The gravitational field outside a black hole is identical to the field produced by any other spherically symmetric object of the same mass. The popular conception of black holes as "sucking" things in is false: objects can orbit around black holes indefinitely without getting any closer. The strange properties of spacetime only become noticeable closer to the black hole.

Event horizon

The effective boundary of a black hole is known as the event horizon. The Event horizon is not a surface, it is the invisible dividing line in space beyond which outside observers cannot see, and from within which matter and energy cannot exit. Stephen Hawking proved that the topology of the event horizon of a non-spinning black hole is a sphere. Due to the extremely strong gravitational field, anything inside the event horizon, including a photon, is prevented from escaping across the event horizon. Particles from

outside this region can fall in, cross the event horizon, and will never be able to leave. In this sense, the event horizon is a little like the point of no return.

External observers cannot probe the interior of a black hole. Consequently according to (non-quantum) general relativity, black holes can be entirely characterized by these parameters: energy, linear momentum, angular momentum, electric charge, and position at a specific time. This principle is summarized by the saying, coined by John Archibald Wheeler, "black holes have no hair" meaning that there are no features that distinguish one black hole from another, other than energy, linear momentum, charge, angular momentum, and location.

Space-time distortion and frame of reference

Objects in a gravitational field experience a slowing down of time, called time dilation. This phenomenon has been verified experimentally in the Scout rocket experiment of 1976, and is, for example, taken into account in the Global Positioning System (GPS). Near the event horizon, the time dilation increases rapidly.

From the viewpoint of a distant observer, an object falling into a black hole appears to slow down, approaching but never quite reaching the event horizon. As the object falls into the black hole, it appears redder and dimmer to the distant observer, due to the extreme gravitational red shift caused by the gravity of the black hole. Eventually, the falling object becomes so dim that it can no longer be seen, at a point just before it reaches the event horizon.

From the viewpoint of the falling object, nothing particularly special happens at the event horizon. The object crosses the event horizon and reaches the singularity at the center within a finite amount of proper time, as measured by a watch carried with the falling observer.

From the viewpoint of the falling observer, distant objects may appear either blue-shifted or red-shifted, depending on the observer's trajectory. Light is blue-shifted by the gravity of the black hole, but is red-shifted by the velocity of the falling object.

Inside the event horizon

Space-time inside the event horizon of an uncharged non-rotating black hole is peculiar in that the singularity is in every observer's future, so all particles within the event horizon move inexorably towards it (Penrose and Hawking). This means that there is a conceptual inaccuracy in the non-relativistic concept of a black hole as originally proposed by John Michell in 1783. In Michell's theory, the escape velocity at the surface of the star is greater than the speed of light, but it would still be theoretically possible to hoist an object out of a black hole using a rope. General relativity eliminates such loopholes, because once an object is inside the event horizon, its time-line contains an end-point to time itself, and no possible world line comes back out through the event horizon. Once inside the black hole, at most one course-correction (performed immediately) is appropriate to maximize your survival time.

As the object continues to approach the singularity, it will be stretched radially with respect to the black hole and compressed in directions perpendicular to this axis. This phenomenon, called spaghettification, occurs as a result of tidal forces: the parts of the object closer to the singularity feel a stronger pull towards it (causing stretching along the axis), and all parts are pulled in the direction of the singularity, which is only aligned with the object's average motion along the axis of the object (causing compression towards the axis).

Singularity

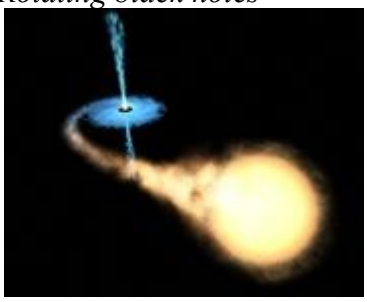
At the center of the black hole, well inside the event horizon, general relativity predicts a singularity, a place where the curvature of spacetime becomes infinite and gravitational forces become infinitely strong.

In a non-rotating black hole, the singularity is one-dimensional, extended in the time direction only. In a rotating black hole, the singularity is two-dimensional, extended in time and in longitude.

It is expected that future refinements or generalizations of general relativity (in particular quantum gravity) will change what is thought about the nature of black hole interiors. Most theorists interpret the mathematical singularity of the equations as indicating that the current theory is not complete, and that new phenomena must come into play as one approaches the singularity.

The cosmic censorship hypothesis asserts that there are no naked singularities in general relativity. This hypothesis is that every singularity is hidden behind an event horizon and cannot be probed. Whether this hypothesis is true remains an active area of theoretical research.

Rotating black holes



An artist's impression of a black hole with a closely orbiting companion star that exceeds its Roche limit. In-falling matter forms an accretion disk, with some of the matter being ejected in highly energetic polar jets.

According to theory, the event horizon of a black hole that is not spinning is spherical, and its singularity is expected to be a single point where the curvature becomes infinite. If the black hole carries angular momentum (inherited from a star that is spinning at the time of its collapse), it begins to drag space-time surrounding the event horizon in an effect known as frame-dragging. This spinning area surrounding the event horizon is called the ergosphere and has an ellipsoidal shape. Since the ergosphere is located outside the event horizon, objects can exist within the ergosphere without falling into the hole. However, because space-time itself is moving in the ergosphere, it is impossible for objects to remain in a fixed position. Objects grazing the ergosphere could in some circumstances be catapulted outwards at great speed, extracting energy (and angular momentum) from the hole, hence the Greek name ergosphere ("sphere of work") because it is capable of doing work.

The singularity inside a rotating black hole is expected to be a ring, rather than a point, though the interior geometry of a rotating black hole is currently not well understood. While the fate of an observer falling into a non-rotating black hole is spaghettification, the fate of an observer falling into a rotating black hole is much less clear. For instance, in the Kerr geometry, an infalling observer can potentially escape spaghettification by passing through an inner horizon. However, it is unlikely that the actual interior geometry of a rotating black hole is the Kerr geometry due to stability

issues, and the ultimate fate of an observer falling into a rotating black hole is currently not known.

Entropy and Hawking radiation

In 1971, Stephen Hawking showed that the total area of the event horizons of any collection of classical black holes can never decrease. This sounded remarkably similar to the Second Law of Thermodynamics, with area playing the role of entropy. Classically, one could violate the second law of thermodynamics by material entering a black hole disappearing from our universe and resulting in a decrease of the total entropy of the universe. Therefore, Jacob Bekenstein proposed that a black hole should have an entropy and that it should be proportional to its horizon area. Since black holes do not classically emit radiation, the thermodynamic viewpoint was simply an analogy. However, in 1974, Hawking applied quantum field theory to the curved spacetime around the event horizon and discovered that black holes can emit Hawking radiation, a form of thermal radiation. Using the first law of black hole mechanics, it follows that the entropy of a black hole is one quarter of the area of the horizon. This is a universal result and can be extended to apply to cosmological horizons such as in de Sitter space. It was later suggested that black holes are maximum-entropy objects, meaning that the maximum entropy of a region of space is the entropy of the largest black hole that can fit into it. This led to the holographic principle.

The Hawking radiation reflects a characteristic temperature of the black hole, which can be calculated from its entropy. This temperature in fact falls the more massive a black hole becomes: the more energy a black hole absorbs, the colder it gets. A black hole with roughly the mass of the planet Mercury would have a temperature in equilibrium with the cosmic microwave background radiation (about 2.73 K). More massive than this, a black hole will be colder than the background radiation, and it will gain energy from the background faster than it gives energy up through Hawking radiation, becoming even colder still. However, for a less massive black hole the effect implies that the mass of the black hole will slowly evaporate with time, with the black hole becoming hotter and hotter as it does so. Although these effects are negligible for black holes massive enough to have been formed astronomically, they would rapidly become significant for hypothetical smaller black holes, where quantum-mechanical effects dominate. Indeed, small black holes are predicted to undergo runaway evaporation and eventually vanish in a burst of radiation.

Although general relativity can be used to perform a semi-classical calculation of black hole entropy, this situation is theoretically unsatisfying. In statistical mechanics, entropy is understood as counting the number of microscopic configurations of a system which have the same macroscopic qualities(such as mass, charge, pressure, etc.). But without a satisfactory theory of quantum gravity, one cannot perform such a computation for black holes. Some promise has been shown by string theory, however. There one posits that the microscopic degrees of freedom of the black hole are D-branes. By counting the states of D-branes with given charges and energy, the entropy for certain supersymmetric black holes has been reproduced. Extending the region of validity of these calculations is an ongoing area of research.

Black hole unitarity

An open question in fundamental physics is the so-called information loss paradox, or black hole unitarity paradox. Classically, the laws of physics are the same run forward or in reverse. That is, if the position and velocity of every particle in the universe were measured, we could (disregarding chaos) work backwards to discover the history of the universe arbitrarily far in the past. In quantum mechanics, this corresponds to a vital property called unitarity which has to do with the conservation of probability.
Black holes, however, might violate this rule. The position under classical general relativity is subtle but straightforward: because of the classical no hair theorem, we can never determine what went into the black hole. However, as seen from the outside, information is never actually destroyed, as matter falling into the black hole appears from the outside to become more and more red-shifted as it approaches (but never ultimately appears to reach) the event horizon.

Ideas of quantum gravity, on the other hand, suggest that there can only be a limited finite entropy (ie a maximum finite amount of information) associated with the space near the horizon; but the change in the entropy of the horizon plus the entropy of the Hawking radiation is always sufficient to take up all of the entropy of matter and energy falling into the black hole.

Many physicists are concerned however that this is still not sufficiently well understood. In particular, at a quantum level, is the quantum state of the Hawking radiation uniquely determined by the history of what has fallen into the black hole; and is the history of what has fallen into the black hole uniquely determined by the quantum state of the black hole and the radiation? This is what determinism, and unitarity, would require.

For a long time Stephen Hawking had opposed such ideas, holding to his original 1975 position that the Hawking radiation is entirely thermal and therefore entirely random, representing new nondeterministically created information. However, on 21 July 2004 he presented a new argument, reversing his previous position. On this new calculation, the entropy associated with the black hole itself would still be inaccessible to external observers; and in the absence of this information, it is impossible to relate in a 1:1 way the information in the Hawking radiation (embodied in its detailed internal correlations) to the initial state of the system. However, if the black hole evaporates completely, then such an identification can be made, and unitarity is preserved. It is not clear how far even the specialist scientific community is yet persuaded by the mathematical machinery Hawking has used (indeed many regard all work on quantum gravity so far as highly speculative); but Hawking himself found it sufficiently convincing to pay out on a bet he had made in 1997 with Caltech physicist John Preskill, to considerable media interest.

Mathematical theory

Black holes are predictions of Albert Einstein's theory of general relativity. There are many known solutions to the Einstein field equations which describe black holes, and they are also thought to be an inevitable part of the evolution of any star of a certain size. In particular, they occur in the Schwarzschild metric, one of the earliest and simplest solutions to Einstein's equations, found by Karl Schwarzschild in 1915. This solution describes the curvature of spacetime in the vicinity of a static and spherically symmetric object, where the metric is,

$$\mathrm{d}s^2 = -c^2\left(1 - \frac{2Gm}{c^2 r}\right)\mathrm{d}t^2 + \left(1 - \frac{2Gm}{c^2 r}\right)^{-1}\mathrm{d}r^2 + r^2\mathrm{d}\Omega^2,$$

where $\mathrm{d}\Omega^2 = \mathrm{d}\theta^2 + \sin^2\theta\,\mathrm{d}\phi^2$ is a standard element of solid angle.

According to general relativity, a gravitating object will collapse into a black hole if its radius is smaller than a characteristic distance, known as the Schwarzschild radius. (Indeed, Buchdahl's theorem in general relativity shows that in the case of a perfect fluid model of a compact object, the true lower limit is somewhat larger than the Schwarzschild radius.) Below this radius, spacetime is so strongly curved that any light ray emitted in this region, regardless of the direction in which it is emitted, will travel towards the centre of the system. Because relativity forbids anything from traveling faster than light, anything below the Schwarzschild radius – including the constituent particles of the gravitating object – will collapse into the centre. A gravitational singularity, a region of theoretically infinite density, forms at this point. Because not even light can escape from within the Schwarzschild radius, a classical black hole would truly appear black.

The Schwarzschild radius is given by

$$r_\mathrm{S} = \frac{2\,Gm}{c^2}$$

where G is the gravitational constant, m is the mass of the object, and c is the speed of light. For an object with the mass of the Earth, the Schwarzschild radius is a mere 9 millimeters - about the size of a marble.

The mean density inside the Schwarzschild radius decreases as the mass of the black hole increases, so while an earth-mass black hole would have a density of 2 × 1030 kg/m3, a supermassive black hole of 109 solar masses has a density of around 20 kg/m3, less than water! The mean density is given by

$$\rho = \frac{3\,c^6}{32\pi m^2 G^3}$$

Since the Earth has a mean radius of 6371 km, its volume would have to be reduced 4 × 1026 times to collapse into a black hole. For an object with the mass of the Sun, the Schwarzschild radius is approximately 3 km, much smaller than the Sun's current radius of about 696,000 km. It is also significantly smaller than the radius to which the Sun will ultimately shrink after exhausting its nuclear fuel, which is several thousand kilometers. More massive stars can collapse into black holes at the end of their lifetimes.

The formula also implies that any object with a given mean density is a black hole if its radius is large enough. The same formula applies for white holes as well. For example, if the visible universe has a mean density equal to the critical density, then it is

a white hole, since its singularity is in the past and not in the future as should be for a black hole.

More general black holes are also predicted by other solutions to Einstein's equations, such as the Kerr metric for a rotating black hole, which possesses a ring singularity. Then we have the Reissner-Nordström metric for charged black holes. Last the Kerr-Newman metric is for the case of a charged and rotating black hole.
There is also the Black Hole Entropy formula:

$$S = \frac{Akc^3}{4\hbar G}$$

Where A is the area of the event horizon of the black hole, $\hbar$ is Dirac's constant (the "reduced Planck constant"), k is the Boltzmann constant, G is the gravitational constant, c is the speed of light and S is the entropy.

A convenient length scale to measure black hole processes is the "gravitational radius", which is equal to

$$r_G = \frac{Gm}{c^2}$$

When expressed in terms of this length scale, many phenomena appear at integer radii. For example, the radius of a Schwarzschild black hole is two gravitational radii and the radius of a maximally rotating Kerr black hole is one gravitational radius. The location of the light circularization radius around a Schwarzschild black hole (where light may orbit the hole in an unstable circular orbit) is 3rG. The location of the marginally stable orbit, thought to be close to the inner edge of an accretion disk, is at 6rG for a Schwarzschild black hole.

Alternative models

Several alternative models, which behave like a black hole but avoid the singularity, have been proposed. But most researchers judge these concepts artificial, as they are more complicated but do not give near term observable differences from black holes (see Occam's razor). The most prominent alternative theory is the Gravastar.
In March 2005, physicist George Chapline at the Lawrence Livermore National Laboratory in California proposed that black holes do not exist, and that objects currently thought to be black holes are actually dark-energy stars. He draws this conclusion from some quantum mechanical analyses. Although his proposal currently has little support in the physics community, it was widely reported by the media.

Among the alternate models are Magnetospheric eternally collapsing objects, clusters of elementary particles (e.g., boson stars), fermion balls, self-gravitating, degenerate heavy neutrinos and even clusters of very low mass (~0.04 solar mass) black holes.

Finally, plasma cosmologists suggest that Bierkland currents provide an alternative explanation for the observed phenomenon. Plasmas transfer energy over great distances to smaller regions where it may be periodically or catastrophically released. Peratt explains the flickering of electromagnetic radiation: "The flickering of a light in Los Angeles does not mean that the supply source, a waterfall or hydroelectric dam in the Pacific Northwest, has abruptly changed dimensions or any other physical property. The flickering comes from electrical changes at the observed load or radiative source, such as

the formation of instabilities or virtual anodes or cathodes in charged particle beams that are orders of magnitude smaller than the supply. Bizarre and interesting non-physical interpretations are obtained if the flickering light is interpreted by a distant observer to be both the source and supply." Plasma cosmology in this manner is a minority view not within mainstream science

Black holes and Earth

Black holes are sometimes listed among the most serious potential threats to Earth and humanity. There are two principal ways in which they could affect Earth.

There is evidence that some black holes are not stationary, rather, they "wander" through space. There is only a very slim possibility that a rogue black hole might pass near, or even through our Solar System. At a typical speed of stars' relative motion in the Milky Way, it would take a few decades for a black hole to traverse the Solar System, during which time it would wreak havoc on planets' orbits, and possibly affect Earth and Sun directly if it passes near them.

Fortunately, any black hole with mass that is large enough to cause problems for Earth would be detected well in advance, possibly hundreds of years before its arrival, by its effect on outer planets' orbits. Small black holes would be much less destructive and would pass through the Solar System relatively unnoticed unless they happen to hit one of the planets.

There is a theoretical possibility that a micro black hole might be created inside a particle accelerator. Again, this is not a cause for concern. Many particle collisions that naturally occur as the cosmic rays hit the edge of our atmosphere are often far more energetic than any collisions created by man. If micro black holes can be created this way, they are already created every day without our involvement.

Even if, say, two protons at the Large Hadron Collider can merge to create a micro black hole, this black hole would be extremely unstable, and it would vaporize due to Hawking Radiation before it had a chance to propagate. For a 14 TeV black hole (the center-of-mass energy at the Large Hadron Collider), direct computation of its lifetime by Hawking formula gives 10-100 seconds.

Gravastar

In astrophysics, the Gravastar theory is a proposal by Pawel Mazur and Emil Mottola to replace the black hole. Instead of a star collapsing into a pinpoint of space with infinite density, the gravastar theory proposes that as an object gravitationally collapses, space itself undergoes a phase transition preventing further collapse, being transformed into a spherical void surrounded by a form of super-dense matter.

The origin of the word "gravastar" is simply: GRAvitational VAcuum STAR. In some references, the word "Condensate" is inserted after vacuum, resulting in "gravacstar".

The Basic Idea

Inside a gravastar, spacetime would be "warped" by the extreme conditions there and the inner space would exert an outward force, like dark energy. Around this void would be a "bubble" of incredibly dense and durable matter. The phase of this matter is theorized to be similar to an extreme form of Bose-Einstein condensate in which all

matter (protons, neutrons, electrons, etc.) goes into what is called a quantum state creating a "super-atom".

Externally, a gravastar appears similar to a black hole: it is visible only by the high-energy emissions it creates while consuming matter. Astronomers observe the sky for X-rays emitted by infalling matter to detect black holes, and a gravastar would produce an identical signature.

Mazur and Mottola have suggested that gravastars could explain very important problems in astrophysics. First, if a black hole cannot form in the real Universe, then there is no difficulty with the black hole information paradox, which is the problem that information seems to disappear. It seems that a gravastar should not suffer from the same problem.

Second, Mazur and Mottola suggest that the violent creation of a gravastar might be an alternate explanation for gamma ray bursts, adding yet one more possibility to the dozens if not hundreds of ideas that have been proposed as the cause of GRBs. Mottola has even suggested that Universe itself could very well be the inside of a giant gravastar, as a possible explanation for the observed accelerating expansion of the Universe.

Carbon Star

A carbon star is a late type giant star similar to the red giants (or occasionally red dwarf) star whose atmosphere contains more carbon than oxygen; the two elements combine in the upper layers of the star, forming carbon monoxide, which consumes all the oxygen in the atmosphere, leaving carbon atoms free to form other carbon compounds, giving the star a "sooty" atmosphere, and a strikingly red appearance to human observers. The spectral characteristics of these stars are quite distinctive, and they were first recognized by their spectra by Angelo Secchi in the 1860's - the pioneer time of astronomical spectroscopy. In "normal" stars (such as the Sun), the atmosphere is richer in oxygen than carbon.

Current research use to subdivide the carbon stars and explain different classes by different astrophysical mechanisms. McClure distinguishes between classical carbon stars, and other non-classical ones that are less massive.

In the classical carbon stars, the abundance of carbon is thought to be a product of helium fusion, specifically the triple-alpha process within a star, which giants reach near the end of their lives in the so called Asymptotic Giant Branch (AGB). These fusion products have been brought to the stellar surface by episodes of convection after the carbon and other products were made. Normally this kind of AGB carbon star fuses hydrogen in a hydrogen burning shell, but in episodes separated by 104-105, the star transform to burning helium in a shell, while the hydrogen fusion temporarily ceases. In this phase, the star's luminosity rises, and material from the inner of the star (notably carbon) moves up. Since the luminosity rises, the star expands so that the helium fusion ceases, and the hydrogen shell burning restarts. During these shell helium flashes, the mass loss from the star is significant, and after many shell helium flashes, an AGB star is transformed into a hot white dwarf and it's atmosphere becomes material for a planetary nebula.

The non-classical kinds of carbon stars are believed to be binary stars, where one star is observed to be a giant star (or occasionally a red dwarf) and the other a white

dwarf. The star presently observed to be a giant star accreted carbon-rich material when it was still a main sequence star from its companion (that is, the star that is now the white dwarf) when the latter was still a classical carbon star. That phase of stellar evolution is relatively brief, and most such stars ultimately end up as white dwarfs. We are now seeing these systems a comparatively long time after the mass transfer event, so the extra carbon observed in the present red giant was not produced within that star. This scenario is also accepted as the origin of the barium stars, which are also characterized as having strong spectral features of carbon molecules and of barium (an s-process element). Sometimes the stars whose excess carbon came from this mass transfer are called "extrinsic" carbon stars to distinguish them from the "intrinsic" AGB stars which produce the carbon internally. Many of these extrinsic carbon stars are not luminous or cool enough to have made their own carbon, which was a puzzle until their binary nature was discovered.

Other less convincing mechanisms, such as CNO cycle unbalancing and Core Helium Flash have also been proposed as mechanisms for carbon enrichment in the atmospheres of smaller carbon stars.

Carbon star spectra

By definition carbon stars have dominant spectral Swan Bands from the molecule C2. Many other carbon compounds use to be present at high levels, such as CH, CN (cyanogen), C3 and SiC2. Carbon is formed in the core and circulated into its upper layers, dramatically changing the layers' composition. Other elements formed through helium fusion and the s-process are also "dredged up" in this way, including lithium and barium.

When astronomers developed the spectral classification of the carbon stars, they got into considerable hardships when trying to correlating the spectra to the stars' effective temperatures. The trouble was all the atmospheric carbon hiding the absorption lines normally used as temperature indicators for the stars.

Secchi

Carbon stars were discovered already in the 1860:ies when spectral classification pioneer Pater Angelo Secchi erected the Secchi class IV for the carbon stars, who in the late 1890:ies were reclassified as N class stars.

Harvard

Using this new Harvard classification, the N class was later enhanced by a R class for less deeply red stars sharing the characteristic carbon bands of the spectrum. Later correlation of this R to N scheme with conventional spectra, showed that the R-N sequence approximately run in parallel with c:a G7 to M10 with regards to star temperature.

MK-type	R0	R3	R5	R8	Na	Nb
giant equiv.	G7-G8	K1-K2	~K2-K3	K5-M0	~M2-M3	M3-M4
Teff	4300	3900	~3700	3450	---	---

Morgan-Keenan C system

The later N classes correspond less well to the counterparting M types, because the Harvard classification was only partially based on temperature, but also carbon abundande; so it soon became clear that this kind of carbon star classification was incomplete. Instead a new dual number star class C was erected so to deal with temperature and carbon abundande. Such a spectrum measured for Y CVn, was determined to be C54, where 5 refers to temperature dependent features, and 4 to the strength of the C2 Swan bands in the spectrum. (C54 is very often alternatively written C5,4).

MK-type	C0	C1	C2	C3	C4	C5	C6	C7
giant equiv.	G4-G6	G7-G8	G9-K0	K1-K2	K3-K4	K5-M0	M1-M2	M3-M4
Teff	4500	4300	4100	3900	3650	3450	---	---

The Revised Morgan-Keenan system

This two-dimensional classification replaced the older R-N classifications during the 1960-1993, but the Morgan-Keenan C system failed to fulfill the creators expectations:

- it failed to correlate to temperature measurements based on infrared,
- originally being twodimensional it was soon enhanced by suffixes, CH, CN, j and other features making it impractical for en-masse analyses of foreign galaxies' carbon star populations,
- and it gradually occurred that the old R and N stars actually were two distinct types of carbon stars, having real astrophysical significance.

A new revised Morgan-Keenan classification was published in 1993 by Philip Keenan, defining the classes: C-N, C-R and C-H. Later the classes C-J and C-Hd were added. This constitutes the established classification system used today:

class	spectrum	population	MV	theory	example(s)
classical carbon stars					
C-R:	the old Harvard class R reborn: are still visible at the blue end of the spectrum, strong isotopic bands, no enhanced Ba line;	medium disc pop I	0	red giants?	S Camelopardalis.
C-N:	the old Harvard class N reborn: heavy diffuse blue absorption, sometimes invisibile in blue, s-process elements enhanced over solar abundance, weak isotopic bands;	thin disc pop I	-2.2	AGB	R Leporis.
non-classical carbon stars					

C-J:	very strong isotopic bands of C2 and CN;	?	?	?	Y Canum Venaticorum.
C-H:	very strong CH absorption;	halo pop II	-1.8	bright giants, mass transfer;	V Arietis, TT Canum Venaticorum
C-Hd:	hydrogen lines and CH bands weak or absent;	thin disc pop I	-3.5	?	HD 137613.

Other qualities

Most classical carbon stars are variable stars: miras, irregular or semiregular variables due to the chaoticity of their modes of fusion.

Observing carbon stars

Due to the insensitivity of night vision to red and a slow adaption of the red sensitive eye rods to the light of the stars, amateur astronomers making magnitude estimates of red variable stars, especially carbon stars, have to know how to deal with the Purkinje effect in order to not overstate the luminosity of the observed star.

Interstellar carbon sowers

Owing to its low gravity, as much as half (or more) of the total mass of a carbon star may be lost by way of powerful stellar winds. The star's remnants, carbon-rich "dust" similar to graphite, therefore become part of the interstellar dust. This dust is believed to be a significant factor in providing the raw materials for the creation of subsequent generations of stars and their planetary systems. The material surrounding a carbon star may blanket it to the extent that the dust absorbs all visible light.

Nova

A nova (pl. *novae*) is a cataclysmic nuclear explosion caused by the accretion of hydrogen onto the surface of a white dwarf star.

If a white dwarf has a close companion star that overflows its Roche lobe, the white dwarf will steadily accrete gas from the star's outer atmosphere. The companion may be a main sequence star, or one that is aging and expanding into a red giant. The captured gases consist primarily of hydrogen and helium, the two principal constituents of ordinary matter in the universe. The gases are compacted on the white dwarf's surface by its intense gravity, compressed and heated to very high temperatures as additional material is drawn in. The white dwarf consists of degenerate matter, and so is largely unresponsive to heat, while the accreted hydrogen is not. The dependence of the hydrogen fusion rate on temperature and pressure means that it is only when it is compressed and heated at the surface of the white dwarf to a temperature of some 20 million K that a nuclear fusion reaction occurs; at these temperatures, hydrogen burns via the CNO cycle. For most binary system parameters, the hydrogen burning is thermally unstable and rapidly converts a large amount of the hydrogen into other heavier elements in a runaway reaction. (Hydrogen fusion can occur in a stable manner on the surface, but only for a narrow range of accretion rates.) The enormous amount of energy liberated by this process blows the remaining gases away from the white dwarf's surface and produces

an extremely bright outburst of light. The rise to peak brightness can be very rapid or gradual which is related to the speed class of the nova ; after the peak the brightness declines steadily. The time taken for a nova to decay by 2 or 3 magnitudes from maximum optical brightness is used to classify a nova via its speed class. A fast nova will typically take less than 25 days to decay by 2 magnitudes and a slow nova will take over 80 days.

In spite of their violence, the amount of material ejected in novae is usually only about 1/10,000th of a solar mass, quite small relative to the mass of the white dwarf. Furthermore, only five percent of the accreted mass is fused to power the outburst. Nonetheless, this is enough energy to accelerate nova ejecta to velocities as high as several thousand kilometers per second--higher for fast novae than slow ones--with a concurrent rise in luminosity from a few times solar to 50,000-100,000 times solar.

A white dwarf can potentially generate multiple novae over time as additional hydrogen continues to accrete onto its surface from its companion star. An example is RS Ophiuchi, which is known to have flared six times (in 1898, 1933, 1958, 1967, 1985, and again in 2006). Eventually, however, either the white dwarf will run out of material, or collapse into a neutron star, or explode as a type Ia supernova.

Occasionally a nova is bright enough and close enough to be conspicuous to the unaided eye. The most recent example was Nova Cygni 1975. This nova appeared on August 29, 1975 in the constellation Cygnus about five degrees north of Deneb and reached magnitude 2.0 (nearly as bright as Deneb). Another recent instance was Nova Cygni 1992, though it was considerably fainter.

Occurrence rate, and astrophysical significance

Astronomers estimate that the Milky Way experiences roughly 20 to 60 novae per year, with a likely rate of about 40. The number of novae discovered each year is much lower, probably due to great distance and observational biases. By comparison, the number of novae discovered each year in the nearby Andromeda Galaxy is much lower; roughly ½ to ⅓ that of the Milky Way.

Spectroscopic observation of nova ejecta nebulae has shown that they are enriched in elements such as helium, carbon, nitrogen, oxygen, neon, and magnesium. Though it would seem that the contributions of novae to the Galaxy might be large over astronomical time scales, this is not the case; in fact, novae supply only 1/50th the amount of material to the interstellar medium as supernovae do, and only 1/200th that of red giant and supergiant stars.

Recurrent novae like RS Ophiuchi (those with periods on the order of decades) are rare. Astronomers theorize however that most, if not all novae are recurrent, albeit on time scales ranging from 1,000 to 100,000 years. The recurrence interval for a nova is less dependent on the white dwarf's accretion rate than on its mass; with their powerful gravity, massive white dwarfs require less accretion to fuel an outburst than lower-mass ones. Consequently, the interval is shorter for high-mass white dwarfs.

Bright novae since 1890

Year	Nova	Maximum brightness
1891	T Aurigae	3.8 mag

1898	V1059 Sagittarii	4.5 mag
1899	V606 Aquilae	5.5 mag
1901	GK Persei	0.2 mag
1903	Nova Geminorum 1903	6 mag
1905	Nova Aquilae 1905	7.3 mag
1910	Nova Lacertae 1910	4.6 mag
1912	Nova Geminorum 1912	3.5 mag
1918	V603 Aquilae	−1.8 mag
1919	Nova Lyrae 1919	7.4 mag
1919	Nova Ophiuchi 1919	7.4 mag
1920	Nova Cygni 1920	2.0 mag
1925	RR Pictoris	1.2 mag
1934	DQ Herculis	1.4 mag
1936	CP Lacertae	2.1 mag
1939	BT Monocerotis	4.5 mag
1942	CP Puppis	0.3 mag
1943	Nova Aquilae 1943	6.1 mag
1950	DK Lacertae	5.0 mag
1960	V446 Herculis	2.8 mag
1963	V533 Herculis	3 mag
1970	FH Serpentis	4 mag
1975	V1500 Cygni	2.0 mag
1975	V373 Scuti	6 mag
1976	NQ Vulpeculae	6 mag
1978	V1668 Cygni	6 mag
1984	QU Vulpeculae	5.2 mag
1986	V842 Centauri	4.6 mag
1991	V838 Herculis	5.0 mag
1992	V1974 Cygni	4.2 mag
1999	V1494 Aquilae	5.03 mag
1999	V382 Velorum	2.6 mag
2006	RS Ophiuchi	4.5 mag

Supernova

A supernova (plural: supernovae) is a stellar explosion which produces an extremely luminous object made of plasma. A supernova may briefly out-shine its entire host galaxy before fading from view over several weeks or months. It would take 10 billion years for the Sun to produce the energy output of an ordinary, Type II supernova. The explosion expels much or all of a star's material with great force, driving a shock wave into the surrounding space, forming a supernova remnant.

There are several different types of supernovae and at least two possible routes to their formation. A massive star may cease to generate energy from the nuclear fusion of atoms in its core, and collapse under the force of its own gravity to form a neutron star or black hole. Alternatively, a white dwarf star may accumulate material from a companion star (either through accretion or a collision) until it nears its Chandrasekhar limit and undergoes runaway nuclear fusion in its interior, completely disrupting it. This second type of supernova is distinct from a surface thermonuclear explosion on a white dwarf, which is called a nova. Solitary stars with a mass below the Chandrasekhar limit, such as the Sun, will evolve into white dwarfs without ever becoming supernovae.

"Nova" is Latin for "new", referring to what appears to be a very bright new star shining in the celestial sphere; the prefix "super" distinguishes this from an ordinary nova, which also involves a star increasing in brightness, though to a lesser extent and through a different mechanism.

History

The earliest recorded supernova, SN 185, was viewed by Chinese astronomers in AD 185. A widely-observed supernova, SN 1054, produced the Crab Nebula. Supernovae SN 1572 and SN 1604, the last to be observed in the Milky Way galaxy, had notable impacts on the development of astronomy in Europe.

Since the development of the telescope, the field of supernova discovery has expanded to other galaxies, starting with the 1885 observation of supernova S Andromedae in the Andromeda galaxy. These events provide important information on cosmological distances. During the twentieth century, successful supernova models for each type of supernovae were developed, and the role of supernova in the star formation process is now increasingly understood.

Most recently it has been discovered that the most distant Type Ia supernovae appeared dimmer than expected. This has provided evidence that the expansion of the universe may be accelerating.

Discovery

The explosion of supernovae in other galaxies cannot be predicted with any meaningful accuracy. When they are discovered, they are already in progress. Most uses for supernovae - as standard candles for measuring distance, for instance—require an observation of their peak luminosity. It is therefore important to discover them well before they reach their maximum. Amateur astronomers, who greatly outnumber professional astronomers, have played an important role in finding supernovae, typically by looking at some of the closer galaxies through an optical telescope and comparing them to earlier photographs.

Towards the end of the 20th century, astronomers increasingly turned to computer-controlled telescopes and CCDs for hunting supernovae. While such systems

are popular with amateurs, there are also larger installations like the Katzman Automatic Imaging Telescope. Recently, the Supernova Early Warning System (SNEWS) project has also begun using a network of neutrino detectors to give early warning of a supernova in the Milky Way galaxy.

Supernova searches fall into two regimes: high redshift and low redshift, with the boundary falling somewhere around a redshift of $z = 0.2$. High redshift searches for supernovae usually involve the observation of Type Ia supernova light curves. These are useful for standard or calibrated candles to generate Hubble diagrams and make cosmological predictions. At low redshift, supernova spectroscopy is more practical than at high redshift, and this information can be used to study the physics and environments of supernovae. Low redshift observations also anchor the low redshift end of the Hubble curve.

Naming Convention

Supernova discoveries are reported to the International Astronomical Union's Central Bureau for Astronomical Telegrams which sends out a circular with the name it assigns to it. The name is formed by the year of discovery, immediately followed by a one or two-letter designation. The first 26 supernovae of the year get an upper case letter from A to Z. Afterward, pairs of lower-case letters are used, starting with aa, ab, and so on. Professional and amateur astronomers find several hundred supernovae per year—341 in 2005 and 529 in 2006. For example, the last supernova of 2005 was SN 2005nc, indicating that it was the 341st supernova found in 2005.

Four historical supernovae are known simply by the year they occurred: SN 1006, 1054, 1572 (Tycho's Nova), and 1604 (Kepler's Star). Beginning in 1885, the letter notation is used, even if there was only one supernova that year (e.g. SN 1885A, 1907A, etc.) - this last happened with SN 1947A. The standard abbreviation "SN" is an optional prefix.

SN 1994D in the NGC 4526 galaxy (bright spot on the lower left). Image by NASA, ESA, The Hubble Key Project Team, and The High-Z Supernova Search Team

Classification

As part of the attempt to understand supernovae, astronomers have classified them according to the lines of different chemical elements that appear in their spectra. The first element for a division is the presence or absence of a line from hydrogen. If a supernova's spectrum contains a hydrogen Balmer line, it is classified Type II, otherwise it is Type I. Among those groups, there are subdivisions according to the presence of other lines and the shape of the light curve (a graph of the supernova's apparent magnitude versus time) of the supernova.

Supernovae taxonomy

Type	Characteristics
Type I	
Type Ia	Lacks hydrogen and present a singly-ionized silicon (Si II) line at 615.0 nm, near peak light.
Type Ib	Non-ionized helium (He I) line at 587.6 nm and no strong silicon absorption feature near 615 nanometers.
Type Ic	Weak or no helium lines and no strong silicon absorption feature near 615 nanometers.
Type II	
Type IIP	Reaches a "plateau" in their light curve
Type IIL	Displays a "linear" decrease in their light curve, where it is "linear" in magnitude versus time, or exponential in luminosity versus time.

The supernovae of Type II can also be sub-divided based on their spectra. While most Type II supernova show very broad emission lines which indicate expansion velocities of many thousands of kilometres per second, some have relatively narrow features. These are called Type IIn, where the "n" stands for "narrow".

A few supernovae, such as SN 1987K and SN 1993J, appear to change types: they show lines of hydrogen at early times, but, over a period of weeks to months, become dominated by lines of helium. The term "Type IIb" is used to describe the combination of features normally associated with Types II and Ib.

Current models

Type Ia

The most commonly accepted theory of this type of supernovae is that they are the result of a carbon-oxygen white dwarf accreting matter from a nearby companion star, typically a red giant.

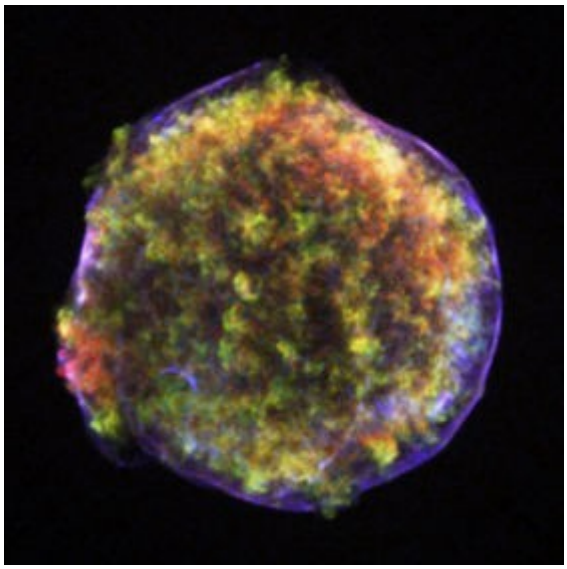
The progenitor binary system consists of main sequence stars, with the primary possessing more mass than the secondary. Being greater in mass, the primary is the first of the pair to evolve onto the asymptotic giant branch, where the star's envelope expands considerably. If the two stars then share a common envelope, the system can lose considerable mass and the angular momentum, orbital radius and period will all be reduced. Once the primary has evolved into a degenerate white dwarf, the secondary star later evolves into a red giant and the stage is set for mass accretion onto the white dwarf. During this final shared envelope phase, the two stars spiral in closer together as angular momentum is lost. The resulting orbit can have a period of only a few hours.

If the accretion continues long enough, the white dwarf may eventually approach the Chandrasekhar limit (1.44 solar masses), the maximum mass that can be supported by electron degeneracy pressure, beyond which the white dwarf would collapse to form a neutron star (if nothing intervened to stop the process).

The current view is that this limit is never actually attained, so that collapse is never initiated. Instead, the increase in pressure raises the temperature near the center, and a period of convection lasting approximately 1,000 years begins. At some point in this simmering phase, a deflagration flame front powered by carbon fusion is born, although the details of the ignition—the location and number of points where the flame begins—is still unknown. Oxygen fusion is initiated shortly thereafter, but this fuel is not consumed as completely as carbon.

Once fusion has begun, the temperature of the white dwarf starts to rise. Normally a typical main sequence star would expand and cool in order to counter-balance an increase in thermal energy. However, degeneracy pressure is independent of temperature, so the white dwarf is unable to regulate the burning process in the manner of normal stars. The flame accelerates dramatically, through the Rayleigh-Taylor instability and interactions with turbulence. It is still a matter of considerable debate as to whether this flame transitions from a subsonic deflagration into a supersonic detonation. Regardless of the exact details of nuclear burning, it is generally accepted that a substantial fraction of the carbon and oxygen in the white dwarf is burned into heavier elements within a period of only a few seconds, raising the internal temperature to billions of degrees.

This energy release from thermonuclear burning (≈1046 joules) is more than enough to unbind the star; that is, the individual particles making up the white dwarf gain enough kinetic energy that they are all able to fly apart from each other. The star explodes violently and releases a shock wave in which matter is typically ejected at speeds on the order of 5-20,000 km/s, or roughly 3% of the speed of light. The energy released in the explosion also causes an extreme increase in luminosity. The typical visual absolute magnitude of Type Ia supernovae is Mv = -19.3 (≈ 5 billion times brighter than Sol), with little variation. Whether or not the supernova remnant remains bound to its companion depends on the amount of mass ejected. As a general rule, the system will remain bound if the remnant is heavier than one half of the original total system mass. If not, the companion will evolve into a runaway star.


Multiwavelength X-ray image of SN 1572 or Tycho's Nova (NASA/CXC/Rutgers/J.Warren & J.Hughes et al.)

The theory of this type of supernovae is similar to that of novae, in which a white dwarf accretes matter more slowly and does not approach the Chandrasekhar limit. In the case of a nova, the infalling matter causes a hydrogen fusion surface explosion that does not disrupt the star.

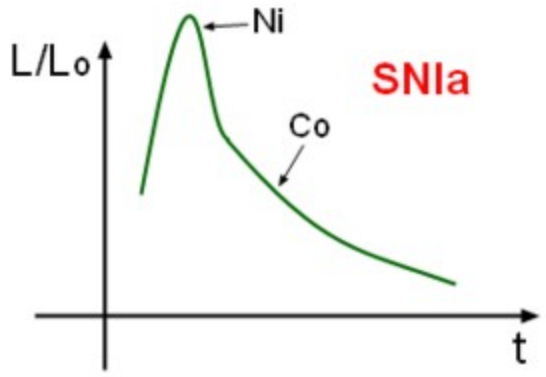
Formation

Unlike the other types of supernovae, Type Ia supernovae generally occur in all types of galaxies, including ellipticals. They show no preference for regions of current stellar formation. As white dwarf stars form at the end of a star's main sequence evolutionary period, such a long-lived star system may have wandered far from the region where it originally formed. Thereafter a close binary system may spend another million years in the mass transfer stage (possibly forming persistent nova outbursts) before the conditions are ripe for a Type Ia supernova to occur.

A second possible, but much less likely, mechanism for triggering a Type Ia supernova is the merger of two white dwarfs. In such a case, the total mass would not be constrained by the Chandrasekhar limit. This is one of several explanations proposed for the anomalously massive (2 solar mass) progenitor of the "Champagne Supernova" (SN 2003fg or SNLS-03D3bb).

Collisions of solitary stars within our galaxy are thought to occur only once every 107–1013 years; far less frequently than the appearance of novae. However, collisions occur with greater frequency in the dense core regions of globular clusters. (C.f. blue stragglers.) A likely scenario is a collision with a binary star system, or between two binary systems containing white dwarfs. This collision can leave behind a close binary system of two white dwarfs. Their orbit decays and they merge together through their shared envelope.

Light curve



This plot of luminosity (relative to the Sun) versus time shows the characteristic light curve for a Type Ia supernova. The peak is primarily due to the decay of Nickel (Ni), while the later stage is powered by Cobalt (Co).

Type Ia supernovae have a characteristic light curve, their graph of luminosity as a function of time after the explosion. Near the time of maximum luminosity, the spectrum contains lines of intermediate-mass elements from oxygen to calcium; these are the main constituents of the outer layers of the star. Months after the explosion, when the outer layers have expanded to the point of transparency, the spectrum is dominated by light emitted by material near the core of the star, heavy elements synthesized during the explosion, most prominently iron-group elements. The radioactive decay of Nickel-56 through Cobalt-56 to Iron-56 produces high-energy photons which dominate the energy output of the ejecta at intermediate to late times.

The similarity in the absolute luminosity profiles of nearly all known Type Ia supernovae has led to their use as a secondary standard candle in extragalactic astronomy. The cause of this uniformity in the luminosity curve is still an open question. In 1998, observations of Type Ia supernovae indicated the unexpected result that the universe seems to undergo an accelerating expansion.

Type Ib and Ic

These events, like supernovae of Type II, are probably massive stars running out of fuel at their centers; however, the progenitors of Types Ib and Ic have lost most of their outer envelopes due to strong stellar winds or else from interaction with a companion. Type Ib supernovae are thought to be the result of the collapse of a massive Wolf-Rayet star. There is some evidence that a few percent of the Type Ic supernovae may be the progenitors of gamma ray bursts (GRB), though it is also believed that any Hydrogen-stripped core-collapse supernova (Type Ib, Ic) could be a GRB, dependent upon the geometry of the explosion.[36]

Type II

Stars far more massive than the sun evolve in much more complex fashions. In the core of the sun, hydrogen is fused into helium, releasing energy which heats the sun's core, and providing pressure which supports the sun's layers against collapse (see hydrostatic equilibrium). The helium produced in the core accumulates there since temperatures in the core are not yet high enough to cause it to fuse. Eventually, as the hydrogen at the core is exhausted, fusion begins to slow down and gravity begins to cause

the core to contract. This contraction raises the temperature high enough to initiate a shorter phase of helium fusion, which accounts for less than 10% of the star's total lifetime. In stars with less than eight solar masses, the carbon produced by helium fusion does not fuse, and the star gradually cools to become a white dwarf. White dwarf stars, if they have a near companion, may then become Type Ia supernovae.

A much larger star, however, is massive enough to create temperatures and pressures needed to cause the carbon in the core to begin to fuse once the star contracts at the end of the helium-burning stage. The cores of these massive stars become layered like onions as progressively heavier atomic nuclei build up at the center, with an outermost layer of hydrogen gas, surrounding a layer of hydrogen fusing into helium, surrounding a layer of helium fusing into carbon (via the triple-alpha process), surrounding layers that fuse to progressively heavier elements. As a star this massive evolves, it undergoes repeated stages where fusion in the core stops, and the core collapses until the pressure and temperature is sufficient to begin the next stage of fusion, reigniting to halt collapse.

Core collapse

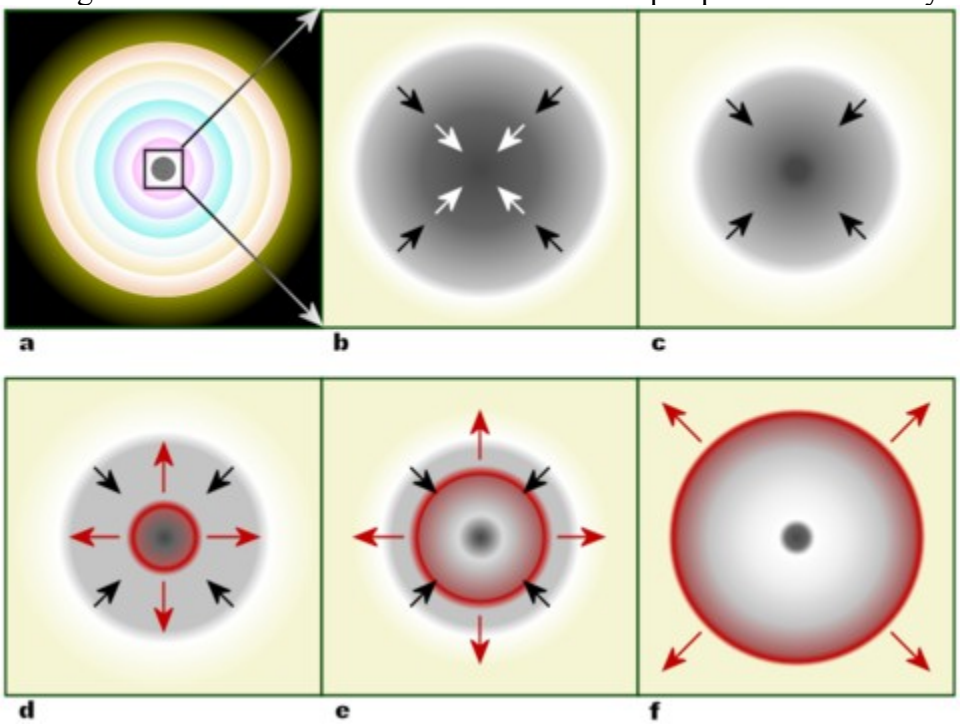
The factor limiting this process is the amount of energy that is released through fusion, which is dependent on the binding energy of these atomic nuclei. Each additional step produces progressively heavier nuclei, which release progressively less energy when fusing, until iron is produced. As iron and nickel have the highest binding energy per nucleon of all the elements, iron cannot produce energy when fused, and an iron core grows. This iron core is under huge gravitational pressure. As there is no fusion to further raise the star's temperature to support it against collapse, it is supported only by degeneracy pressure of electrons. When the core's size exceeds the Chandrasekhar limit, degeneracy pressure can no longer support it, and catastrophic collapse ensues.

The outer part of the core reaches velocities of up to 70,000 km/s (0.23c) as it collapses toward the center of the star. The rapidly shrinking core heats up, producing high energy gamma rays which decompose iron nuclei into helium nuclei and free neutrons (via photodissociation). As the core's density increases, it becomes energetically favorable for electrons and protons to merge via inverse beta decay, producing neutrons and neutrinos. The neutrinos escape from the core, carrying away energy and further accelerating the collapse, which proceeds in milliseconds as the core detaches from the outer layers of the star. Some of these neutrinos are absorbed by the star's outer layers, beginning the supernova explosion.

For Type II supernovae, the collapse is eventually halted by short-range repulsive neutron-neutron interactions mediated by the strong force, as well as by degeneracy pressure of neutrons, at a density comparable to that of an atomic nucleus. Once collapse stops, the infalling matter rebounds, producing a shock wave that propagates outward. The energy from this shock dissociates heavy elements within the core. This reduces the energy of the shock, which can stall the explosion within the outer core.

The core collapse phase is known to be so dense and energetic that only neutrinos are able to escape. Most of the gravitational potential energy of the collapse gets converted to a ten second neutrino burst, releasing about 1046 joules (100 foes). Of this energy, about 1044 Joule (1 foe) is reabsorbed by the star producing an explosion. This energy revives the stalled shock, which blows off the rest of the star's material. The

neutrinos produced by a supernova have been actually observed in the case of Supernova 1987A leading astronomers to conclude that the core collapse picture is basically correct.



Within a massive, evolved star (a) the onion-layered shells of elements undergo fusion, forming an iron core (b) that reaches Chandrasekhar-mass and starts to collapse. The inner part of the core is compressed into neutrons (c), causing infalling material to bounce (d) and form an outward-propagating shock front (red). The shock starts to stall (e), but it is re-invigorated by neutrino interaction. The surrounding material is blasted away (f), leaving only a degenerate remnant.

When the progenitor star is below about 20 solar masses (depending on the strength of the explosion and the amount of material that falls back), the degenerate remnant of a core collapse is a neutron star. Above this mass the remnant collapses to form a black hole. The theoretical limiting mass for this type of core collapse scenario is about 40–50 solar masses. Above that mass, a star is believed to collapse directly into a black hole without forming a supernova explosion.

Type II and theoretical models

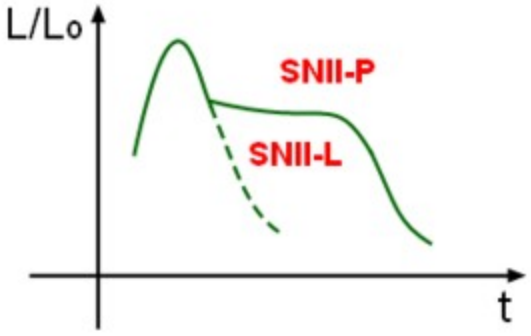
The energy per particle in a supernova is typically one to one hundred and fifty picojoules (tens to hundreds of MeV). The per-particle energy involved in a supernova is small enough that the predictions gained from the Standard Model of particle physics are likely to be basically correct, but the high densities may include corrections to the Standard Model. In particular, Earth-based particle accelerators can produce particle interactions which are of much higher energy than are found in supernovae, but these experiments involve individual particles interacting with individual particles, and it is likely that the high densities within the supernova will produce novel effects. The interactions between neutrinos and the other particles in the supernova take place with the weak nuclear force which is believed to be well understood. However, the interactions

between the protons and neutrons involve the strong nuclear force which is much less well understood.

The major unsolved problem with Type II supernovae is that it is not understood how the burst of neutrinos transfers its energy to the rest of the star producing the shock wave which causes the star to explode. From the above discussion, only one percent of the energy needs to be transferred to produce an explosion, but getting that one percent of transfer has proven very difficult. In the 1990s, one model for doing this involved convective overturn, which suggests that convection, either from neutrinos from below, or infalling matter from above, completes the process of destroying the progenitor star. Heavier elements than iron are formed during this explosion by neutron capture, and from the pressure of the neutrinos pressing into the boundary of the "neutrinosphere", seeding the surrounding space with a cloud of gas and dust which is richer in heavy elements than the material from which the star originally formed.

Neutrino physics, which is modeled by the Standard Model, is crucial to the understanding of this process. The other crucial area of investigation is the hydrodynamics of the plasma that makes up the dying star; how it behaves during the core collapse determines when and how the "shock wave" forms and when and how it "stalls" and is reenergized. Computer models have been very successful at calculating the behavior of Type II supernovae once the shock has been formed. By ignoring the first second of the explosion, and assuming that an explosion is started, astrophysicists have been able to make detailed predictions about the elements produced by the supernova and of the expected light curve from the supernova. However some aspects of the supernova light curves remain unexplained.

Light curves and unusual spectra



This graph of the luminosity (relative to the Sun) as a function of time shows the characterisic shapes of the light curves for a Type II-L and II-P supernova.

The light curves for Type II supernovae is distinguished by the presence of hydrogen Balmer absorption lines in the spectra. These light curves have an average decay rate of 0.008 magnitudes per day; much lower than the decay rate for Type I supernovae. Type II are sub-divided into two classes, depending on whether there is a plateau in their light curve (Type II-P) or a linear decay rate (Type II-L). The net decay rate is lower at 0.012 magnitudes per day for Type II-L compared to 0.0075 magnitudes per day for Type II-P. The difference in the shape of the light curves is believed to be

caused, in the case of Type II-L supernovae, by the expulsion of most of the hydrogen envelope of the progenitor star.

The plateau phase in Type II-P supernovae is due to a change in the opacity of the exterior layer. The shock wave ionizes the hydrogen in the outer envelope, which greatly increases the opacity. This prevents photons from the inner parts of the explosion from escaping. Once the hydrogen cools sufficiently to recombine, the outer layer becomes transparent.

Of the Type II supernovae with unusual features in their spectra, Type IIn supernovae may be produced by the interaction of the ejecta with circumstellar material. [55] Type IIb supernovae are likely massive stars which have lost most, but not all, of their hydrogen envelopes through tidal stripping by a companion star. As the ejecta of a Type IIb expands, the hydrogen layer quickly becomes optically thin and reveals the deeper layers.

Hypernovae (Collapsars)

The core collapse of sufficiently massive stars may not be halted. Degeneracy pressure and repulsive neutron-neutron interactions can only support a neutron star whose mass does not exceed the Tolman-Oppenheimer-Volkoff limit of very roughly 4 solar masses. Above this limit, the core collapses to directly form a black hole, perhaps producing a (still theoretical) hypernova explosion. In the proposed hypernova mechanism (known as a collapsar) two extremely energetic jets of plasma are emitted from the star's rotational poles at nearly light speed. These jets emit intense gamma rays, and are one of many candidate explanations for gamma ray bursts.

See more information below.

Asymmetry

A long-standing puzzle surrounding supernovae has been a need to explain why the degenerate remnant of the explosion is given a substantial velocity component away from the core. This kick can be fairly substantial, propelling an object that is more massive than the Sun at a velocity of 500 km/s or greater. This displacement is believed to be caused by an asymmetry in the explosion, but the mechanism by which this momentum is transferred to the neutron star remnant has remained a puzzle. The leading explanation for this kick is some combination of a hydrodynamic or magnetic effect, and an interaction with a massive burst of neutrinos generated during the explosion.

This composite image shows X-ray (blue) and optical (red) radiation from the Crab Nebula's core region. A pulsar near the center is propelling particles to almost the speed of light. This neutron star is traveling at an estimated 375 km/s. NASA/CXC/HST/ASU/J. Hester et al. image credit.

The asymmetry in the explosion is thought to be caused by large-scale convection above the core. The convection can create variations in the densities of elements, resulting in uneven burning during the collapse, bounce and resulting explosion. The asymmetry of the explosion can create highly directional jets, propelling matter at a high velocity out of the star. These jets may play a crucial role in the resulting supernova explosion.

Initial asymmetries has also been confirmed in Type Ia supernova explosion through observation. This result may mean that the initial luminosity of this type of supernova may depend on the viewing angle. However the explosion becomes more symmetrical with the passage of time. Early asymmetries may be detectable by measuring slight differences in the polarization of the emitted light.

Type I versus Type II

A fundamental difference between Type I and Type II supernovae is the source of energy for the radiation emitted near the peak of the light curve. The progenitors of Type II supernovae are stars with extended envelopes that can attain a degree of transparency with a relatively small amount of expansion. Most of the energy powering emission at peak light is derived from the shock wave that heats and ejects the envelope.

The progenitors of Type I supernovae, on the other hand, are compact objects much smaller (but more massive) than the Sun that must expand (and therefore cool) enormously before becoming transparent. Heat from the explosion is dissipated in the expansion and is not available for light production. The radiation emitted by Type I supernovae is thus entirely attributable to the decay of radionuclides produced in the explosion, principally nickel-56 (with a half-life of 6.1 days) and its daughter cobalt-56 (with a half-life of 77 days). Gamma rays emitted during the decays are absorbed by the ejected material, heating it to incandescence.

As the material ejected by a Type II supernova expands and cools, radioactive decay eventually takes over as the main energy source for light emission in this case also.

A bright Type Ia supernova may expel 0.5-1.0 solar masses of nickel-56, while a Type Ib, Ic or Type II supernova probably ejects closer to 0.1 solar mass of Nickel-56.

Interstellar impact

Source of heavy elements

Supernovae are a key source of elements heavier than oxygen. These elements are produced by fusion (for iron fifty-six, 56Fe, and lighter elements), and by nucleosynthesis during the supernova explosion for elements heavier than iron. The synthesis of heavy nuclei within a supernova occurs a result of the r-process, which is a rapid form of nucleosynthesis that occurs under conditions of high temperature and high density of neutrons. The reactions produce highly unstable nuclei that are rich in neutrons. These forms are unstable and rapidly beta decay into more stable forms.

The r-process reaction in supernovae produces about half of all the element abundance beyond iron, including plutonium, uranium and californium. The only competing process for producing elements heavier than iron is the s-process in large, old red giant stars, which produces these elements much more slowly, and which cannot produce elements heavier than lead.

Role in stellar evolution

The remnant of the supernova explosion consists of a compact object and a rapidly expanding shock wave of material. This cloud of material sweeps up the surrounding interstellar medium during a free expansion phase, which can last for up to two centuries. The wave then gradually undergoes a period of adiabatic expansion, and will slowly cool and mix with the surrounding interstellar medium over a period of about 10,000 years.

In standard astronomy, the Big Bang produced hydrogen, helium, and traces of lithium, while all heavier elements are synthesized in stars and supernovae. Supernovae tend to enrich the surrounding interstellar medium with metals, which for astronomers means all of the elements other than hydrogen and helium and is a different definition than that used in chemistry.

Supernova remnant N 63A lies within a clumpy region of gas and dust in the Large Magellanic Cloud. NASA image.

These injected elements ultimately enriching the molecular clouds that are the sites of star formation. Thus, each stellar generation has a slightly different composition, going from an almost pure mixture of hydrogen and helium to a more metal-rich composition. Supernovae are the dominant mechanism for distributing these heavier

elements, which are formed in a star during its period of nuclear fusion, throughout space. The different abundances of elements in the material that forms a star have important influences on the star's life, and may decisively influence the possibility of having planets orbiting it.

The kinetic energy of an expanding SNR can trigger star formation due to compression of nearby, dense molecular clouds in space. However the increase in turbulent pressure can also prevent star formation if the cloud is unable to lose the excess energy.

Evidence from daughter products of short-lived radioactive isotopes shows that a nearby supernova helped determine the composition of the Solar System 4.5 billion years ago, and may even have trigger the formation of this system. Supernova production of heavy elements over astronomic periods of time ultimately made the chemistry of life on Earth possible.

Impact on Earth

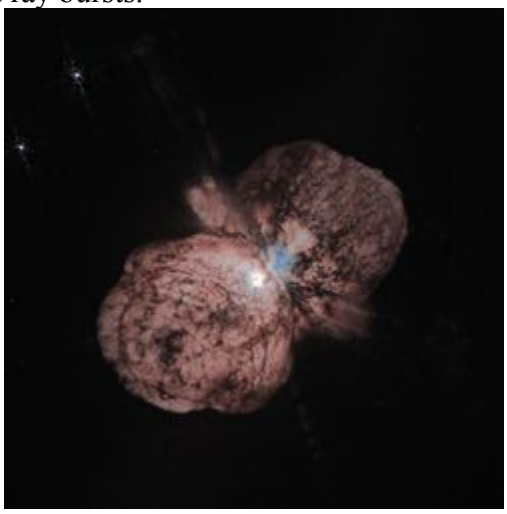
A near-Earth supernova is an explosion resulting from the death of a star that occurs close enough to the Earth (roughly fewer than 100 light-years away) to have noticeable effects on its biosphere. Gamma rays are responsible for most of the adverse effects a supernova can have on a living terrestrial planet. In Earth's case, gamma rays induce a chemical reaction in the upper atmosphere, converting molecular nitrogen into nitrogen oxides, depleting the ozone layer enough to expose the surface to harmful solar and cosmic radiation. The gamma ray burst from a nearby supernova explosion has been proposed as the cause of the end Ordovician extinction, which resulted in the death of nearly 60% of the oceanic life on Earth.

Speculation as to the effects of a nearby supernova on Earth often focuses on large stars, such as Betelgeuse, a red supergiant 427 light-years from Earth which is a Type II supernova candidate. Several prominent stars within a few light centuries from the Sun are candidates for becoming supernovae in as little as a millennium. Though spectacular, these "predictable" supernovae are thought to have little potential to affect Earth. Type Ia supernovae, though, are thought to be potentially the most dangerous if they occur close enough to the Earth. Because Type Ia supernovae arise from dim, common white dwarf stars, it is likely that a supernova that could affect the Earth will occur unpredictably and take place in a star system that is not well studied. One theory suggests that a Type Ia supernova would have to be closer than a thousand parsecs (3300 light years) to affect the Earth.

Recent estimates predict that a Type II supernova would have to be closer than eight parsecs (twenty-six light years) to destroy half of the Earth's ozone layer. Such estimates are mostly concerned with atmospheric modeling and considered only the known radiation flux from SN 1987A, a Type II supernova in the Large Magellanic Cloud. Estimates of the rate of supernova occurrence within 10 parsecs of the Earth vary from once every 100 million years to once every one to ten billion years.
In 1996, astronomers at the University of Illinois at Urbana-Champaign theorized that traces of past supernovae might be detectable on Earth in the form of metal isotope signatures in rock strata. Subsequently, iron-60 enrichment has been reported in deep-sea rock of the Pacific Ocean by researchers from the Technical University of Munich.

Hypernova

A hypernova is many times more violent than a supernova. Hypernova (pl. hypernovae) refers to an exceptionally large star that collapses at the end of its lifespan —for example, a collapsar, or a large supernova. Up until the 1990s, it had a more specific meaning to refer to an explosion with released energy of over 100 supernovae (10^{46} joules). Such explosions were proposed to explain the exceptional brightnesses of gamma ray bursts.


Eta Carinae, in the constellation of the Careens, the one of the nearer candidates for a hypernova

Collapsing star

The core of the hypernova collapses directly into a black hole and two extremely energetic jets of plasma are emitted from its rotational poles at nearly the speed of light. These jets emit intense gamma rays, and are a candidate explanation for gamma ray bursts. In recent years a great deal of observational data on gamma ray bursts significantly increased our understanding of these events, and made clear that the collapsar model produces explosions that differ only in detail from more or less ordinary supernovae. Nevertheless, they continue to sometimes be referred to in the literature as hypernovae.

Since stars sufficiently large to collapse directly into a black hole are quite rare, hypernovae would likewise be rare, if they indeed occur. It has been estimated that a hypernova would occur in our galaxy every 200 million years.

Collapsar is the name of a hypothetical model where a fast-rotating Wolf-Rayet star with a massive (greater than 30 solar masses) core collapses to form a large, rotating black hole, drawing in the surrounding envelope of stellar matter at relativistic speeds with a Lorentz factor of around 150. These speeds would make collapsars the fastest known celestial objects. They may be considered to be "failed" Type Ib supernovae.
It is believed that collapsars are the cause of long (> 2 seconds) gamma-ray bursts, since powerful energy jets would be created along the rotation axis of the black hole, creating a burst of high-energy radiation to an observer whose line of sight is along the jet.
A possible example of a collapsar is the supernova Sn1998bw, which was associated with the gamma-ray burst GRB980425. This was classified as a type Ic supernova due to its unusual spectral properties in the radio spectrum, indicating the presence of relativistic

matter. However, it should be noted that Sn1998bw was an unusual supernova, and that GRB980425 was an unusual gamma-ray burst.

Planets

Many stars have planets orbiting around them. Planets can typically be broken down into groups by similar properties.

Classification

In the year 2006, the IAU (International Astronomical Union) set forth rules to define what constitutes a planet. A planet must meet the following rules:

1) must be in orbit around a star
2) must have sufficient mass for its self-gravity to overcome rigid body forces to achieve hydrostatic equilibrium (the body is nearly spherical)
3) has "cleared the neighborhood" of its orbit (removed the majority of other objects)
4) must not be orbiting another planet

If all four points are met, the object is a planet. If point 3 is not met, the object is a dwarf planet. Those that do not meet point 2 (and likely the others) are "small solar system bodies". This ruling reclassified Pluto from a planet to a dwarf planet.

It was argued that these rules are inaccurate, since earth, Mars, Jupiter and Neptune all have not completely cleared their orbits. Earth has some 10,000 near-earth asteroids while Jupiter has over 100,000 trojan asteroids in its orbital path. If Neptune had cleared its orbital path completely, Pluto would have been ejected from the system entirely. Further arguments exist in regards to Pluto's moon Charon; in that the moon is massive enough that it could qualify as a dwarf planet of its own, making Pluto and Charon a binary planet, and together they have a small moon or two orbiting the pair.

Terrestrial

Planets (and possibly dwarf planets) that are similar to Earth - with bodies largely composed of rock: Mercury, Venus, Earth and Mars. If including dwarf planets, Ceres would also be counted, with as many as three other asteroids that might be added as of January 2008.

Terrestrial planets all have roughly the same structure: a central metallic core, mostly iron, with a surrounding silicate mantle. The moon is similar, but lacks an iron core. Terrestrial planets have canyons, craters, mountains, and volcanoes. Terrestrial planets possess secondary atmospheres - atmospheres generated through internal vulcanism or comet impacts, as opposed to the gas giants, which possess primary atmospheres - atmospheres captured directly from the original solar nebula.

Theoretically, there are two types of terrestrial or rocky planets, one dominated by silicon compounds and another dominated by carbon compounds, like carbonaceous chondrite asteroids. These are the silicate planets and carbon planets (or "diamond planets") respectively.

Carbon

A carbon planet has no oxygen in the atmosphere and has large amounts of carbon based compounds. Thus such a planet has oceans of gasoline, and might rain propane one

day and rain butane the next. There is no fear of explosions or ignition, as there is no oxygen. Furthermore, such a planet would be rich in coal and diamonds.

Gas Giant

Planets with a composition largely made up of gaseous material and are significantly more massive than terrestrials: Jupiter and Saturn.

A gas giant may have a rocky or metallic core - in fact, such a core is thought to be required for a gas giant to form - but the majority of its mass is hydrogen and helium, with traces of water, methane, ammonia, and other hydrogen compounds. (Although familiar to us as gases on Earth, these constituents are assumed to be compressed into liquids or solids deep in a gas giant's atmosphere.) Other theories state that there is no solid core, but rather, the gas itself is under such heat and pressure as to form a semi-solid state called metallic gas. Thus the "core" of Jupiter is likely to be metallic hydrogen.

The four solar system gas giants share a number of features. All have atmospheres that are mostly hydrogen and helium and that gradually blend into the liquid interior at pressures greater than the critical pressure, so that there is no clear boundary between atmosphere and body. In this regard, our four gas giants exemplify the classic "matter phase-gradient" in the materials sciences. They have very hot interiors, ranging from about 7,000 kelvin (K) for Uranus and Neptune to over 20,000 K for Jupiter. This great heat means that beneath their atmospheres the planets are most likely entirely liquid metallic hydrogen. Thus, when discussions refer to a "rocky core," one should not picture a ball of solid rock, or even (at 20,000 K) liquid rock. Rather, what is meant is a region in which the concentration of heavier elements such as iron and nickel is greater than that in the rest of the planet.

All four planets rotate relatively rapidly, which causes wind patterns to break up into east-west bands or stripes. These bands are prominent on Jupiter, muted on Saturn and Neptune, and barely detectable on Uranus.

All four planets are accompanied by elaborate systems of rings and moons. Saturn's rings are the most spectacular and were the only ones known before the 1970s. As of 2006, Jupiter is known to have the most moons with sixty-three.

Ice Giant

Ice giants are a sub-class of gas giants, distinguished from gas giants by their depletion in hydrogen and helium, and a significant composition of rock and ice: Uranus and Neptune.

Uranus and Neptune have distinctly different interior compositions, with the bulk of their interiors thought to consist of a mixture (or layered assortment) of rock, water, methane, and ammonia. Like Jupiter and Saturn, the outer atmosphere contains mainly hydrogen in its troposphere. Very hazy atmosphere layers with a small amount of methane gives them aquamarine colors such as baby blue and ultramarine colors respectively. Both have magnetic fields that are sharply inclined to their axes of rotation.

The rather misleading term has caught on because planetary scientists typically use 'rock', 'gas', and 'ice' as shorthands for classes of elements and compounds commonly found as planetary constituents, irrespective of what phase they appear in. In the outer solar system, hydrogen and helium are "gases"; water, methane, and ammonia are "ices"; and silicates are “rock”. When deep planetary interiors are considered, it may not be far

off to say that, by "ice" astronomers mean oxygen and carbon, by "rock" they mean silicon, and by "gas" they mean hydrogen and helium.

Chthonian

This is another sub-class of gas giant, in which their hydrogen and helium atmospheres are blown away by strong stellar winds. As of early 2008, no such planet has been found, although planet HD 209458b in the Pegasus constellation (150 lightyears away) is in the process of becoming a chthonian planet.

Dwarf

Objects that are composed mainly of ice, and do not have large planetary masses. The dwarf planets Pluto, Ceres, Haumea, Makemake and Eris are ice dwarfs, and several dwarf planetary candidates also qualify. Such dwarf planets range 400 to 975 km in diameter. As of the IAU's definition of a dwarf planet in August 2006, five planets were declared dwarf planets and it is believed there may be as many as 200 more in the Kupier belt and scattered disc.

Oceanic

Such a planet is completely covered by oceans of liquid. One such planet has been found as of 2009 that is twice the size of earth and believed to be 85% water, covering the entire planet's surface.

Formation

It is not known with certainty how planets are formed. The prevailing theory is that they are formed from those remnants of a nebula that do not condense under gravity to form a protostar. Instead, these remnants become a thin, protoplanetary disk of dust and gas revolving around the protostar and begin to condense about local concentrations of mass within the disc known as planetesimals. These concentrations become ever more dense until they collapse inward under gravity to form protoplanets. After a planet reaches a diameter larger than the Earth's moon, it begins to accumulate an extended atmosphere. This serves to increase the capture rate of the planetesimals by a factor of ten.

When the protostar has grown such that it ignites to form a star, its solar wind blows away most of the disc's remaining material. Thereafter there still may be many protoplanets orbiting the star or each other, but over time many will collide, either to form a single larger planet or release material for other larger protoplanets or planets to absorb. Those objects that have become massive enough will capture most matter in their orbital neighborhoods to become planets. Meanwhile, protoplanets that have avoided collisions may become natural satellites of planets through a process of gravitational capture, or remain in belts of other objects to become either dwarf planets or small solar system bodies.

The energetic impacts of the smaller planetesimals will heat up the growing planet, causing it to at least partially melt. The interior of the planet begins to differentiate by mass, developing a denser core. Smaller terrestrial planets lose most of their atmospheres because of this accretion, but the lost gases can be replaced by

outgassing from the mantle and from the subsequent impact of comets. (Smaller planets will lose any atmosphere they gain through various escape mechanisms.)

The level of metallicity is now believed to determine the likelihood that a star will have planets. Hence it is thought less likely that a metal-poor, population II star will possess a more substantial planetary system than a metal-rich population I star.

Planetary Attributes

All the planets revolve around the Sun in the same direction - counter-clockwise as seen from over the Sun's north pole. The period of one revolution of a planet's orbit is known as its year. A planet's year depends on its distance from the Sun; the farther a planet is from the Sun, not only the longer the distance it must travel, but also the slower its speed, as it is less affected by the Sun's gravity.

The planets also rotate around invisible axes through their centers. The period of one rotation of a planet is known as its day. All the planets rotate in a counter-clockwise direction, except for Venus, which rotates clockwise. There is great variation in the length of day between the planets, with Venus taking 243 Earth days to rotate, and the gas giants only a few hours.

Planets also have varying degrees of axial tilt; they lie at an angle to the plane of the Sun's equator. This causes the amount of sunlight received by each hemisphere to vary over the course of its year; when the northern hemisphere points away from the Sun, the southern hemisphere points towards it, and vice versa. Each planet therefore possesses seasons; changes to the climate over the course of its year. The point at which each hemisphere is farthest/nearest from the Sun is known as its solstice. Each planet has two in the course of its orbit; when a planet's northern hemisphere has its summer solstice, when its day is longest, the southern has its winter solstice, when its day is shortest. Jupiter's axial tilt is very small, so its seasonal variation is minimal; Uranus, on the other hand, has an axial tilt so extreme it is virtually on its side, which means that its hemispheres are either perpetually in sunlight or perpetually in darkness around the time of its solstices.

All of the planets have atmospheres as their large masses mean gravity is strong enough to keep gaseous particles close to the surface. The larger gas giants are massive enough to keep large amounts of the light gases Hydrogen and Helium close by, although these gases mostly float into space around the smaller planets. Earth's atmosphere is greatly different to the other planets because of the various life processes that have transpired there, while the atmosphere of Mercury has mostly, although not entirely, been blasted away by the solar wind.

Many of the planets have natural satellites, called "moons", regardless of their size. The gas giants all have numerous moons in complex planetary systems. Many gas giant moons have similar features to the terrestrial planets and dwarf planets, and some have been studied for signs of life.

Dwarf Planets

Before the August 2006 decision, several objects were proposed by astronomers, including at one stage by the IAU, as planets. However in 2006 several of these objects were reclassified as dwarf planets, objects distinct from planets. Currently three dwarf planets in the Solar System are recognized by the IAU: Ceres, Pluto and Eris. Several

other objects in both the asteroid belt and the Kuiper belt are under consideration, with as many as 50 that could eventually qualify. There may be as many as 200 that could be discovered once the Kuiper Belt has been fully explored. Dwarf planets share many of the same characteristics as planets, although notable differences remain - namely that they are not dominant in their orbits.

By definition, all dwarf planets are members of larger populations. Ceres is the largest body in the asteroid belt, while Pluto is a member of the Kuiper belt and Eris is a member of the scattered disc. According to Mike Brown there may soon be over forty trans-Neptunian objects that qualify as dwarf planets under the IAU's recent definition.

Extrasolar Planets

Of the 209 extrasolar planets (those outside the Solar System) discovered to date (November 2006) most have masses which are about the same as, or larger than, Jupiter's the planets orbiting the stars Mu Arae, 55 Cancri and GJ 436 which are approximately Neptune-sized, and a planet orbiting Gliese 876 that is estimated to be about 6 to 8 times as massive as the Earth and is probably rocky in composition.

It is far from clear if the newly discovered large planets would resemble the gas giants in the Solar System or if they are of an entirely different type as yet unknown, like ammonia giants or carbon planets. In particular, some of the newly discovered planets, known as hot Jupiters [a planet with the mass or greater of Jupiter, but eight times closer to their star than Mercury], orbit extremely close to their parent stars, in nearly circular orbits. They therefore receive much more stellar radiation than the gas giants in the Solar System, which makes it questionable whether they are the same type of planet at all. There is also a class of hot Jupiters that orbit so close to their star that their atmospheres are slowly blown away in a comet-like tail: the Chthonian planets [hypothetical planet where a gas giant has its hydrogen and helium atmosphere stripped away, leaving a metallic core].

Several projects have been proposed to create an array of space telescopes to search for extrasolar planets with masses comparable to the Earth. The NASA Terrestrial Planet Finder was one such program, but (as of 2006-02-06) this program has been put on indefinite hold. The ESA is considering a comparable mission called Darwin. The frequency of occurrence of such terrestrial planets is one of the variables in the Drake equation which estimates the number of intelligent, communicating civilizations that exist in our galaxy.

In 2005, astronomers detected a planet in a triple star system, a finding that challenges current theories of planetary formation. The planet, a gas giant slightly larger than Jupiter, orbits the main star of the HD 188753 system, in the constellation Cygnus, and is hence known as HD 188753 Ab. The stellar trio (yellow, orange, and red) is about 149 light-years from Earth. The planet, which is at least 14% larger than Jupiter, orbits the main star (HD 188753 A) once every 80 hours or so (3.3 days), at a distance of about 8 Gm, a twentieth of the distance between Earth and the Sun. The other two stars whirl tightly around each other in 156 days, and circle the main star every 25.7 years at a distance from the main star that would put them between Saturn and Uranus in the Solar System. The latter stars invalidate the leading hot Jupiter formation theory, which holds that these planets form at "normal" distances and then migrate inward through some

debatable mechanism. This could not have occurred here; the outer star pair would have disrupted outer planet formation.

Interstellar Planets

Several computer simulations of stellar and planetary system formation have suggested that some objects of planetary mass would be ejected into interstellar space. Some scientists have argued that such objects found roaming in deep space should be classed as "planets". However, many others argue that only planemos that directly orbit stars should qualify as planets, preferring to use the terms "planetary body", "planetary mass object" or "planemo" for similar free-floating objects (as well as planetary-sized moons). The IAU's working definition on extrasolar planets takes no position on the issue. The discoverers of the bodies mentioned above decided to avoid the debate over what constitutes a planet by referring to the objects as planemos. However, the original IAU proposal for the 2006 definition of planet favored the star-orbiting criterion, although the final draft avoided the issue.

For a brief time in 2006, astronomers believed they had found a binary system of such objects, Oph 162225-240515, which the discoverers described as "planemos". However, recent analysis of the objects has determined that their masses are each greater than 13 Jupiter-masses, making the pair brown dwarfs.

<u>You Are Here</u>

Ok this all said and done, our sun, a metal rich population I red dwarf star, formed around 5 billion years ago when the universe was around 8-9 billion years old. It is assumed our star followed the typical star formation process (outlined elsewhere).

From the remaining gasses formed some planets; 4 terrestrial, 2 gas giants and 2 ice giants. Also formed are the asteroid field, Kuiper belt and as many as a half dozen dwarf planets and a couple hundred moons. On one of these terrestrial planets, the conditions were just right to lead to a series of events that allowed life to form and thrive.

After some severe weather changes and several hundreds of thousands of years, we arrive to 2012.

Construction Tables

Ok with that long college lesson over, here are the tables for randomly generating a star system. This is not a “quick” roll process, so it really should be done ahead of time. If a roll makes no sense based on information above, reroll. If there are options not available in some combinations, it will be noted below. If the GM does not wish to go with chance, they can simple pick what results they want and adjust as needed.

This section may change as I study more about stellar mechanics. This list is by no means exhaustive, and the GM can find more stars here:
http://en.wikipedia.org/wiki/Category:Star_types

The Star

The first step is determining the type of star or stars in the system. Based on real observations by astronomers, approximately 80% of the stars in the Milky Way are believed to be red dwarf stars. Furthermore, it is believed that 30% to 50% of all star systems are binary stars. Star systems with multiple stars may still have planets, although

the more stars a system has, the less likely planets are going to exist since they are more likely to be ejected from a system. Systems of three stars are quite common, although four or more becomes more rare (they throw one or more out of the group).

Table 1: System Type [roll table 2 for each star]

d100	
1-55	Single star
56-94	Binary star
95-97	Trinary star
98-00	Star cluster

Star Cluster contains 1d6+3 stars, typically in binary/trinary groups orbiting each other (such as the Alcyone system or Gamma Velorum).

Table 2: Star Type

d100	
1-65	Main Sequence [Table 3]
66-90	Post-Main Sequence [Table 4]
91-95	Pre-Main Sequence [Table 5]
96-00	Oddities

This should be rolled for each star in a multiple-star system. It is not implausible for a red dwarf to be paired to a blue giant.

Oddities can include things such as Wolf-Rayet stars or any other type of extremely rare or currently (as of 2009) theoretical stars.

Table 3: Main Sequence Stars

d100	
1-85	Red Dwarf
86-92	Orange Dwarf
93-98	Yellow Dwarf
99-00	Blue Dwarf

Table 4: Post-Main Sequence Stars

d100	
1-65	Giant
66-78	Supergiant
79-89	Hypergiant
90-00	Compact

Table 5: Pre-Main Sequence Stars

d100	
1-25	T-Tauri
26-50	Herbig Ae/Be
51-94	FU Orinis
95-00	Protostar

Table 6: Giant Stars

d100	
1-35	Red Giant
36-48	Carbon Star
49-56	C-H Star
57-75	Yellow
76-83	Blue
84-88	Barium Star

89-00	Subgiant

A barium star is binary with a carbon star. If this result is rolled, count the two stars as a single "slot" on the original chart roll.

A subgiant star is between a dwarf and giant star in size/mass.

Table 7: Supergiant Stars

d100	
1-45	Red
46-78	Yellow
79-82	Blue
83-00	Bright Giant

A bright giant is between a supergiant and giant in size/mass.

Table 8: Hypergiant Stars

d100	
1-46	Red
47-67	Yellow
68-82	Blue
83-00	White

Table 9: Compact Stars

d100	
01-09	Dying
10-45	White Dwarf
46-57	Neutron Star
58-65	Magnetar
66-69	Exotic Star
70-80	Black Hole
81-00	Blazar

A dying star is one that has started fusing iron and has 3d10 hours until it goes nova.

The Planets

To determine how many planets are in a star system, roll 2d6 and apply the following modifiers (if the result becomes 0 or lower, there are no planets):

-2 for each star beyond the first
-5 if there is even one compact star
+1 if the original roll was a single star

Table 1: Planet Type (roll once for each planet)

d100	
01-09	Cthonian
10-35	Dwarf planet
36-46	Terrestrial
47-57	Gas giant
58-68	Ice giant
69-75	Ocean planet
76-82	Hot Jupiter
83-90	Asteroid belt
91-99	Carbon planet
00	Eccentric Jupiter

If an eccentric Jupiter is rolled, no planets in the system will be Earth-mass or smaller.

Some Example Star Systems

Alcyone

Alcyone is a complex quintuple (5) star system. The primary, Alcyone-A, is a blue-white B-type giant binary star separated by 0.031 arcseconds (the distance between Sol and Jupiter). Alcyone-B and Alcyone-C are a pair of 8th magnitude white dwarf stars (Alcyone-C is a Delta Scuti type variable star) separated from Alcyone-A by 117 and 181 arcseconds, respectively. Alcyone-D is yellow-white dwarf star at 191 arcseconds from the primary.

Such a complex system is unlikely to have any planets, since the contradicting gravitic pull would most likely eject any planets from the system. If it does have any planets, they are well beyond the range to support life.

Gamma Velorum

This system consists of no less than six stars. The primary star γ Velorum A is a spectroscopic binary consisting of a blue supergiant class O9 (30 solar masses) and a massive Wolf-Rayet star (approximately 10 solar masses) separated at about 1 AU. The second brightest is γ Velorum B, which is a blue-white B-type subgiant, which can only be differentiated from the primary with use of binoculars or better. Next out is γ Velorum C, a white A-type star 62.3 arcseconds from the primary. The next is another binary star consisting of γ Velorum D (white A-type star) and γ Velorum E (a 13th magnitude star) separated by 1.8 arcseconds.

Capella

Capella is a pair of binary stars. The primary is a spectroscopic binary consisting of two G-class giants separated by only 100 million km. The other is a binary pair of two M-class red dwarf stars about 1 LY away.

Rho Cassiopeiae

This is a yellow hypergiant star in the Cassipoeiae constellation. In the year 2000, it was observed to have dropped in temperature from 7000K to 4000K over the course of a few months and had ejected approximately 3% of its solar mass. It seems to have these eruptions every 50 or so years, meaning another such would have likely occurred by 2050. Considering the star is 8150 LY away from earth, it may have already gone supernova by the time of the campaign setting.

Gliese 581c

This planet is believed to be the first extrasolar “near earth” planet within a star’s habitable zone. It orbits a red dwarf planet Gliese 581, which is 20.4 lightyears from earth towards the constellation Libra. Discovered on April 24, 2007.

The planet is measured (at the time of discovery) to be 5.03 earth masses. If the planet is rocky with an iron core, then it would be approximately 50% larger than earth and have 2.24G. If the planet is icy or watery, then it would be around twice the size of earth and have 1.25G.

Gliese 581 c has an orbital period ("year") of 13 Earth days and its orbital radius is only about 7% that of the Earth, about 11 million km, while the Earth is 150 million

kilometers from the Sun. Since the host star is smaller and colder than the Sun - and thus less luminous - this distance places the planet on the "warm" edge of the habitable zone around the star according to Udry's team . A typical radius for an M0 star of Gliese 581's age and metallicity is 0.00128 AU, against the sun's 0.00465 AU. This proximity means that the primary star should appear 3.75 times wider and 14 times larger in area for an observer on the planet's surface looking at the sky than the Sun appears to be from Earth's surface.

Chapter 14 – Aliens

For the most part, Macross is all about Protoculture; humans and Zentraedi share the same genetic structure, so they can be considered one race. The only other aliens to show up in Macross have been the Protoculture (human progenitor?), Zentraedi (human variant), Zolans (likely another Protoculture link), the Protodeviln (extra-universe) and the Vajra (intergalactic). However, the NUNS has only explored a small fraction of the Milky Way galaxy. Who knows what else is hiding out there?

Additionally, the aliens rules can also be used in Robotech, which is host to nearly a dozen species already.

Building an Alien

The first thing to keep in mind is whether or not the alien race will be available for PCs to play as. In Macross, PCs may be Zentraedi and Zolan, but not Vajra. If the alien race is going to be purely NPC, you can make them as powerful as you like (Q from Star Trek anyone?). However, if you want to allow them for PCs, you need to make sure they are roughly the same power level as other PC races.

Modifications

Aliens are set apart from humans by Boons and Flaws. Humans could be considered to be "middle of the road", therefore any Boon would make the alien better than a human while any Flaw would make them weaker than a human.

For every rank of Boon, the alien race must have equal ranks of Flaws. If they have a Major Boon, they could have a Major Flaw or three Minor Flaws.

In addition to the Boons and Flaws below, an alien race can have Talents and Complications found in the basebook. For instance, a warrior race might all have High Pain Threshold but suffer from the Berserker complication.

Boons

Inhuman Stats: The alien race has stats higher than humans.

Minor: Up to 3 stats may have a limit of 12
Greater: Up to 5 stats may have a limit of 15
Major: Any number of stats may have a limit of 20

Flight: The alien race is capable of self-propelled flight. The MA uses Mekton scale.

Minor: MA up to 2
Greater: MA up to 6
Major: MA up to 12

Armor: Through dense skin, chitinous exoskeleton or natural forcefield, the alien race can shrug off damage. All SP is in human scale and applies to all body locations.

Minor: SP 5
Greater: SP 10
Major: SP 15

Natural Weapons: The alien race possesses claws, fangs, bladed tails or other features. All weapons inflict Hits damage.
Minor: Melee weapons up to 1d6 damage
Greater: Melee weapons up to 2d6 damage
Major: Melee or ranged weapons up to 3d6 damage or "shock" weapons

Psychic Power: The alien race has natural psionic talents.
Minor: Up to 3 powers
Greater: Up to 6 powers
Major: Up to 10 powers

Environmental Protection: The alien race is immune or highly resistant to a particular environmental hazard.
Minor: Immune to heat or cold
Greater: Immune to vacuum and explosive decompression
Major: Immune to radiation

Flaws

Inhuman Stats: The alien race has lower stats than humans.
Minor: Up to 3 stats have a limit of 7.
Greater: Up to 5 stats have a limit of 5.
Major: Up to 7 stats have a limit of 3.

Racial Prejudice: The alien race has an adverse reputation.
Minor: Some other races dislike this race and will avoid them.
Greater: Most other races dislike this race and will avoid them.
Major: All races seem to universally hate this race and will react with violence.

Environmental/Special Needs: The alien race has non-human needs that must be kept up.
Minor: Breathes an uncommon atmosphere and requires a respirator off their homeworld.
Greater: Needs a special or rare food/liquid to survive.
Major: Can only survive in a specialized environment or diet and must have a full environmental habitat wherever they go.

Social Restrictions: The alien race has different moral codes than is common, and strictly adhere to them.
Minor: Pacifist. The alien race will not harm others.
Greater: Arrogant. Any insult is met with combat to the death.
Major: Inscrutable. The alien race is just so "alien" that they are incomprehensible to other races.

Skill Restriction: The alien race has trouble with some human skills due to their "inhuman" nature. For instance, a race of energy beings may not understand physical skills, while a warrior race may have "weeded out" Empathy based skills for being weak.
Minor: -2 penalty to one skill group
Greater: -4 penalty to one skill group
Major: -8 penalty to one skill group

Cultural Attitudes

The last step is to determine the attitude of the "average" member of the society. Borrowing from Robotech, the Praxians are a race of all-female amazon-like warriors. The average Praxian is a proud, strong warrior with a sense of martial honor. They value strength and combat prowess.

God-like Aliens

So your campaign needs a "godlike" alien of such unimaginable power that they seem to be magical. First off, figure out what you want your alien to do. Then have them do it. If they are *that* powerful, they don't need to roll dice.

Isn't being a GM fun?

Non-Human Aliens

The vast majority of aliens in anime are near-human or even human. Oftentimes the "alien" race is a lost colony of humans or were transplanted from Earth long ago. Why is this?

First off, anime is a Japanese invention, and the Japanese are big on getting the pathos points for empathizing with the "enemy". A common plot is that the unidentified "alien" invaders are only seen for their mecha and capital ships until 1/3 to 1/2 way into the series, then they are revealed as humans or near-humans. This makes the heroes have to face the fact they are fighting what they see as themselves. Remember how the heroes felt in Macross and Southern Cross when they discovered who the "enemy" was.

The second main reason is plain old sex. Another anime staple is one of the heroes becoming romantically attached with one of the "aliens". In Macross, Max was instantly smitten with Millia's exotic beauty, and in Southern Cross, Bowie became attached to Musika. It's hard to get it on with a giant slug. Yuk..

Advanced Aliens

The above is good for quick and simple aliens, but sometimes we want a little more meat to the campaign. Maybe the above is good for one-shot disposable aliens, but what if the aliens are to be a permanent, and prominent, part of the campaign? The following advanced rules can be used for detailing out your alien civilizations.

Billions and Billions of Stars

Seeing pictures of millions of stars makes one feel small, and yet even such a picture shows but a small pinprick of the universe. It is believed that there are billions of galaxies, each with billions upon billions of stars. Each of those stars has the potential for planets, and each of those planets has the possibility of life of some form. Eventually one or more of those life forms will develop the advanced technology required for space exploration.

The Drake Equation

This equation, formulated by Dr. Frank Drake and expanded by Dr. Carl Sagan, formulates through logical deductions and reasonable scientific assumptions, the number of worlds in our galaxy, the number of potential civilizations, and the number of these civilizations which are advanced enough to have developed space flight.

The formula takes in to account the number of stars in our galaxy (N), the fraction of these stars which may have planetary systems (f_p), the number of planets in such a system which can harbor life (n_e), the fraction of suitable planets on which life does arise (f_l), the fraction of these planets on which intelligent life arises (f_i), the fraction of planets with intelligent life that develops a civilization (f_c), and the fraction of a planetary life time graced by a technical civilization (f_L). The actual equation is ($N \times f_p \times n_e \times f_l \times f_i \times f_c \times f_L$), where N is a constant (the number of stars), and all f values are all fractions.

We know N is equal to four hundred billion (4×10^{11}). All other numbers are hypothetical, and thus, can be adjusted to suit any conceivable sci-fi campaign. Reasonable assumptions for these values are expressed below. These are the numbers as proposed by Dr. Carl Sagan.

$N = 4 \times 10^{11}$ $f_p = 0.3$ (assuming most stars harbor planets)
$n_e = 2$ (in our system Earth and Mars could harbor life)
$f_l = 0.3$ (an education assumption)
$f_i = 0.1$ (an educated assumption)
$f_c = 0.1$ (an educated assumption)
$f_L = 0.00000001$

If you are wondering why f_L is so low (one millionth of a percent), it is because our civilization has existed for less time than a millionth of the lifespan of our world. Civilization on our world has only existed for, perhaps, six to seven thousand years, out of the four billion the world has been here (seven thousand divided by 4 billion is a very small number). Technological civilization has only existed for a hundred years (now divide 100 by 4 billion and you see what I mean!). Therefore, 1 millionth of a percent is a very, very optimistic assumption.

At any rate, when this number is computed ($4 \times 10^{11} \times 0.3 \times 2 \times 0.3 \times 0.1 \times 0.1 \times 0.00000001$) the result is 7.2. To make things simple, this number is rounded up to ten. This means that, at present, there are probably ten technologically advanced civilizations in our galaxy. But don't forget, there are hundreds of billions of galaxies just like ours!

The GM may adjust these numbers as he wishes. For instance, if the GM assumes that a technological civilization will exist for 1000 years, f_L can be increased to just 0.0000001, which would in turn make the result equal 100 advanced civilizations in our galaxy. Other adjustments would likewise give rise to other such changes. Below is a more "cinematic" universe, where there are many alien civilizations:
$N = 4 \times 10^{11}$
$f_p = 0.3$ (assuming most stars harbor planets)
$n_e = 2$ (in our system Earth and Mars could harbor life)
$f_l = 0.5$ (an generous assumption)
$f_i = 0.3$ (an optimistic assumption)
$f_c = 0.3$ (an educated assumption)
$f_L = 0.0000001$

In this setting, the galaxy would harbor ($4 \times 10^{11} \times 0.3 \times 2 \times 0.5 \times 0.3 \times 0.2 \times 0.0000001$) 1080 alien civilizations. We shall consider this to be 1000 civilizations, for simplicity. The distribution of alien civilizations would still be extremely small, with a density of 1 civilization every three million cubic lightyears (or spaced out from each other with a distance of two thousand light-years apart). This may be insufficient for a viable sci-fi campaign. The GM may continue to make adjustments to the Drake formula to suit his universe, or simply declare how many civilizations exist. Nevertheless, the Drake formula is a good guideline to follow, especially for a hard sci-fi campaign.

Cinematic Civilizations

In a space opera, sci-fantasy or action adventure campaign, it would not be unreasonable to assume there are thousands or tens of thousands of alien races. In Star Wars there are hundreds of alien species, and only a handful of them are detailed out.

In such a universe, four assumptions are made.

1) the formation of stars inherently gives rise to the formation of planets
2) all main sequence stars have at least one planet in the "biozone"

3) life will almost always arise on such planets, assuming they have a suitable atmosphere

4) eventually intelligent life and civilization will appear and last for a long time

With these assumptions, the Drake Formula can generate anywhere in the range of 50,000 to 100,000 alien civilizations. At this point, the density of civilizations becomes practical for a space adventure (average of 200-300 lightyears between civilizations). If each of these civilizations travel 300 lightyears in all directions, they would eventually collide with each other, thus creating war, conflict and epic sagas.

Setting	Number of Civilizations
Sagan Estimate	7-10
Hard Sci-Fi	700-1000
Pulp Sci-Fi	3000-10,000
Abundant	10,000-50,000
Cinematic	100,000+
Super-Cinematic	1,000,000+

So even in a campaign with a million alien civilizations, the campaign could take place in a smaller area of 1000 lightyears across, containing 10-20 alien civilizations.

For example, in Robotech the Sentinels, the Local Group contains the Praxians, Garudans, Spherisians, Perytonians, Tirolians, Karbarrans and Invid. The story also speaks of the V'loxia, who were wiped out. So even this small galactic area already has a half dozen alien species already, and there is more area to explore!

Worlds to Explore

First off, there are three main types of aliens in science fictions. The first class are from worlds of independent, self-contained evolution. These aliens are radically different from anything on earth, and extremely difficult to envision without falling into the "Monster Alien Menace from Galoopa Prime" stereotype. The second, more common approach is panspermia (explained below). The third type is "thoughtless"; that is the writer doesn't care how or why the aliens evolved, and just invents them as he likes with no science behind it. The third class will not be covered in this, as anyone can just make crap up on a whim.

Star Type

There are many different kinds of stars, ranging from tiny red dwarfs up to superbright blue-white hypergiants. While this is covered very in-depth in Chapter 13, we will just retouch with some simple information here. Star classification ranges from O to M.

O	blue stars
B	blue-white stars
A	white stars
F	yellow-white stars
G	yellow stars
K	orange stars
M	red stars

Realistically class O, B and A stars cannot have planets where life evolves because of the immense output of radiation, and such giant stars don't last long enough (class O stars can last as few as 4-5 million years). That leaves class F, G and K have a higher probability of life evolving in their system. Most class M stars shouldn't have life; they produce very little radiation which is good for life but bad for evolution. Fortunately most class M stars last for 10-15 billion years, giving plenty of time for evolution chances.

All stars also have a sub-class, listed 0-9, where 0 is hotter and brighter and 9 is cooler and dimmer. Star classes will further have a suffix of a Roman numeral rated I, II, III, IV, V or VI, indicating their size; I are supergiants, IV are subgiants, V is similar to our sun, and VI are dwarf stars. For instance, our sun is G2V.

Possible habital zones range from F0V to M5V. Once the star type is determined, then determine the number and placement of the planets. Based on our solar system, there should be 2d6 planets for a star similar to ours.

Orbits are rated in AUs (astronomical units) which is equal to roughly 93 million miles or 150 million km. Earth is 1 AU from our parent star. According to the Titius-Bode Formula, the placement of orbits runs at a ratio of 0, 3, 6, 12, 24, 48, 96, 192, 384 and 768. The ratio number is added to 4 and then divided by 10 for the AU of the orbit.

*For the first orbit, we compute 0 +4 and divide by 10 for 0.4, which is the orbit of Mercury (0.4 AU).

*The second orbit is 3 +4 and divide by 10 for 0.7, which is the orbit of Venus (0.7 AU).

*The third orbit is 6 +4 and divide by 10 for 1, which is our orbit (1 AU).
And this continues for our solar system, with the asteroid belt as our 5th orbit.

To add variation, the added constant B (4 for our solar system) could change. You can roll 1d6 for the constant, or assign it by star type; F would be 5, G would be 4 (as ours), K would be 3 and M would be 2.

The Biozone

This is the most important aspect of the star system for placing the homeworld of your alien civilization. The biozone is the range where liquid water exists on the planet. It is sometimes called the Goldielocks Zone, as it is "not too hot, not too cold, just right".

For a class G star, this zone is 0.7 to 1.6 AU. In our solar system earth is right in the middle, with Venus and Mars at the extreme edges. At best, 1-3 planets will fall into this zone.

Star Type	Biozone
F	1.8-3.0 AU
G	0.7-1.6 AU
K	0.5-0.8 AU
M	0.1-0.3 AU

Planetary Attributes

There are many attributes to consider. Just because a planet is the 3rd orbit of a G2 star doesn't mean it will be identical to earth. Factors to consider are size of the planet, gravity, planet type (gas, ice, terran), climate range (desert, frozen, oceanic), terrestrial compounds (high metallic core, iron core, silicate, etc), rotation period,

seasons, length of day and year, number of moons, size/number of continents, size/number of moons, atmosphere type (earthlike, methane, CO_2, ammonia, etc) and many other things.

Remember that exotic aliens can evolve on exotic worlds (such as a hot, heavy gravity, fluorine atmosphere). These factors will greatly influence the creation of that alien civilization.

Moons

Many science fiction writers will try to make a world more exotic by giving them multiple moons. After all, Mars has two moons right? The problem is, as explained in Chapter 13, that our moon is the exotic one. By many accounts our moon is large enough in comparison to our planet that some alien civilizations would call it a binary planet.

When a planet forms, it will pull most of the material into itself, leaving a very small amount for moons. Because of the early impact with a Mars-sized planet, the Earth and its moon effectively had two planet's worth of material to share. Most "earth-like" planets will likely have a single moon which is a captured asteroid of some type.

Multi-Star System

Just to retouch from Chapter 13.. the more stars that are in a single star system, the likelihood of life evolving goes down. Simply put, more stars means more radiation. Add this to the fact that the multiple gravity wells of multiple stars makes for some eccentric orbits, and may well throw most of their planets out of the system completely.

In a hard-science sci-fi setting such systems can be written off for the possibility of life. However, in a space-opera or science-fantasy setting, anything is possible.

Panspermia

No, it's not a dirty word. Panspermia is a scientific term meaning that life starts from one point in a galaxy and spreads outward in the form of microbes, usually travelling on comets or meteorites and seeds on multiple worlds or that an alien civilization has seeded its own on various planets (sounds like the Protoculture).

This is not as far-fetched as it first sounds. Consider the example of the now-famous Mars rock. The microbes on the Mars rock were fossils and long dead for a billion years before it landed on earth. But *what if* a rock was blown off a planet rich with life and hurled into space. You may be quick to say most life would be killed by the force of the impact or it would not survive in space. Certainly, a microbe cannot live in the frozen vacuum of space. However, microbes can hibernate. It has been scientifically proven that some bacteria can remain in a state of frozen metabolic activity for tens of millions of years only to awaken when placed in the presence of a livable environment. So a chunk of rock from a planet full of life gets blasted into space and the bacteria on it goes into hibernation until it lands on another planet, then wakes up and begins multiplying.

Another possibility is that the chemical process for life began on comets. Comets are rich in water and hydrocarbons, exposed to massive doses of heat and stellar radiation. It is plausible that under the right conditions, a chemical reaction could occur on a comet that creates the basic blocks of life. If all it takes is a dirty snowball being

exposed to intense radiation to create life, then many such reactions could be set off on hundreds of thousands of such comets. Eventually some of them will crash into planets.

The third possibility is localized panspermia. In this theory, a region of space perhaps a few lightyears across is a nebula of cometary fragments (such as our Oort Cloud). These fragments may be comets or debris from a failed planet, holding hibernating microbes or proto-microbe organics. When star systems pass through this region of space, their planets are bombarded with thousands of these fragments.

Finally, there is the possibility of *intelligence guided* panspermia. Going with the hard-science Drake Formula, life evolves on perhaps a dozen planets in the entire galaxy. One of those develops advanced technology to travel throughout the region of space, seeding planets with suitable environments with the life of their homeworld. Eventually the progenitor race vanishes, leaving the transplanted life to grow on their own paths.

Why Panspermia?

The reason for this theory in science fiction is two-fold. First off, it *might* be the way it really happened. Second, this is a convenient way of making multiple alien species seem so.. human.

For example, in Star Trek it is explained humans, Vulcans, Romulans, Klingons, Andorians, etc all originated from the same original species millions of years ago. Watch enough episodes of Stargate and Stargate: Atlantis and you see planets with oak trees, you hear the sparrows and oddly enough they all have mosquitoes. Running into a dozen near-human species makes the really alien aliens stand out.

Another example, using Robotech. In the Local Group of the sentinels storyline, most of the races were near human or close to human. The Tirolians, Praxians and Zentraedi all had virtually identical genetics as humans, making them all the same "race". This is further emphasized with their link to the pretoxican precursor race. The Karbarrans and Garudans are humanoid with animal features, while the Perytonians are human-like with physical differences. Only the Haydonites and Spherisians are non-human, with the former being cybernetic with no information on what they were beforehand, and the latter being effectively crystal forms animated by bacterial colonies. Oh yes, the Invid are giant slugs.

All of this leaves the simple method of waving a magic wand and declaring the alien race is near human because of panspermia and be done with it. This of course leads to two possible types of evolution. The first is ancient microbe evolution, insuring that all the races will be of similar biology but will have enough differences to not be "human", such as animal features. This can still lead to "exotics" as described below, but can still survive in human environments. The second is recent humanoid evolution, where the progenitor race seeds multiple worlds to evolve just slightly different from each other, leaving room for blue-skinned humans, "elves" and four armed humanoids.

<u>Xeno-Exotics</u>

Rarely seen in science fiction, yet the most probable form, exotic aliens are life forms with radically different biologies from anything on earth. While much of this section is based on scientific understanding, everything described is pure speculation. Feel free to let your imagination run wild, but don't lose total sight of the basic principles of physics, chemistry and biology.

Panspermia Exotics

As explained above, panspermia exotics are aliens that evolved from universally common base microbes, but the evolution was radically different. In such a setting, alien worlds will be exotic and alien, but at least they will have some common features (think of Pandora from Avatar). All panspermia exotics should still be based on Earth-like standards; they will be carbon-based, require liquid water, breath an oxygen or CO_2 atmosphere and have a spiral DNA code like humans. They will reproduce sexually, although it could be asexual (keep in mind asexual reproduction does not facilitate rapid evolution).

Panspermia exotics lie at the fringe of what we can imagine for truly alien aliens. Most of these aliens are envisioned to be giant bugs, slugs, squids or jellyfish-heads, which is unrealistic, though unavoidable.

To actually make up an alien world based on Earth biology, the best thing to do is create it a timeline of evolution, starting from microbe and evolving step-by-step, making sure to change a few things on the way.

At this point it should be noted that there is now evidence that two different panspermia comets hit Earth. There are two radically different types of microbes and cell structures seen on Earth. The first, most ancient kind, is called prokaryotic (which appeared around 3 billion years ago). Prokaryotic microbes have no nucleus structure and are primarily simple bacteria. The other kind, called eukaryotic appeared around 1.7 billion years ago. They are more complex bacteria which evolved into higher multi-cellular life forms such as plants and animals.

Once your alien world is evolved to be *dissimilar* to earth, pick one of the life forms and make it sentient. Now write up their history, culture and civilization. Figure out their technology level and how they got there.

Xeno Exotics

Truly alien aliens are the stuff of Hugo and Nebula awards. They are rarer than gold in sci-fi and prized above all because they are the result of brilliant imagination and genius. Most xeno-exotics have radically different biologies, a highly alien and often terrifying appearance and a mentality utterly beyond human comprehension. They are *alien*.

The key to xeno-exotics is imagination. These may be evolved from exotic bacteria, such as bacterial colonies around deep ocean vents, or sulfate-ingesting argon-excreting microbes. Even so, such life would *still* be a panspermia exotic. A xeno-exotic would be even more bizarre. Life must be evolved from a base chemical reaction to a state of sentience, over the course of billions of years. Chlorine based life could form on a world with an exotic chlorinate atmosphere. Methane based life has been proposed for decades, as has silicone based life. Creatures of dark matter, anti-matter, quantum matter or even pure energy. Sentient worlds, sentient stars and even regions of space where consciousness simply arises can come into play. Perhaps even a race of self-replicating machine intelligences, the last survivors (or conquerors) of the progenitor race... Remember, xeno-exotics are alien... *Alien*.

Threshold of the Imagination

Once you have decided on the type of aliens in your universe, it is necessary to develop them and their world. If you want a race of militant, hive-mentality bugs, this is probably unnecessary. The world should already be developed, assuming you developed the race by step-by-step evolution. Assuming it is, the alien race had to develop higher intelligence at some point in the past, going from primitive "cave dwellers" to a civilized species.

Don't fall into the sad old cliché that any non-Earth planet has one species, one language, one religion, one culture, blah. Here I must differentiate between race and ethnic race. An alien race, in our terms, is an alien species, of which there can be multiple ethnic races. Humans are a species, so are elves. Asians are an ethnic race of humans, and Drow elves are an ethnic species of elves. There are many ethnic races of humans, so there should be the same for an alien species. Some ethnic races will have different characteristics for any given species. In fact, two or more sentient species could develop on the same planet, perhaps on separate continents. This would play an extremely significant factor in both culture's development.

Let's take a look at Macross. The Protoculture was the first sentient humanoid species in the galaxy. They used their own DNA to clone the Zentraedi, and they "modified" the ancient life of Earth for future colonization. Thus it could be said that humans and Zentraedi are in fact ethnic races of the Protoculture species. In Robotech, the Zentraedi and Robotech Masters are cloned from the Tirolians. The Tirolians and Praxians were transplanted from Earth by the Pretoxicans. Thus again, the Tirolians, Robotech Masters, Zentraedi and Praxians are all ethnic races of the human species. The Garudans, Perytonians and Karbarrans *might* be evolved from humans, given the interference of Haydon. Wild isn't it?

Genetic Engineering

Simply put, it is the manipulation of DNA to achieve the desired traits. At basic levels it is used to correct for genetic flaws. At the upper end it is cloning specifically tailored life forms. In our current time, circa 2012, we are already cloning mice and using artificial insemination. We are beginning to clone meat that was never part of a cow. So if we can do that little now, a civilization centuries ahead of us could do much more.

In fact, much of the basis of Macross lies on the concept of cloning. The Protoculture cloned themselves, and genetically engineered a clone race of warriors called the Zentraedi. After the Zentraedi reduce the human population to a fraction of its original size, Earth began using mass cloning of humans to restore the population to viable levels. Furthermore, the Protoculture visited Earth no less than *twice* and modified the humanoid life they found to better suit their needs.

With this in mind, encountering a near-human alien species might not be the actual species, but rather genetically engineered "ambassadors to humanity" given a form we would be most comfortable dealing with what with our delicate (and inferior) psychology. Referencing Mospeada, the Refless turns some of her Inbit into human forms to interact with humans.

Types of Aliens

As discussed in great detail earlier, there are several different categories of aliens seen in science fiction literature. This ranges from the utterly silly to the scientifically

plausible. Depending on the campaign, a certain level of Factuality level is called for. Factuality level is similar to reality level, however since it is pure speculation, the best we can hope for is to gauge realism in terms of facts and educated guesses. That is to say, it is extremely unlikely that "little green men" exist, not because they are little or green, but because they are men. However, it is within the realm of scientific conjecture that me way one day meet up with an alien of an extremely exotic nature, radically different than anything seen on earth.

There is no "factuality dial" per say, rather the factuality level is an abstraction which should be part of the GM's process in developing an alien species. Even if the Gm decides for a "pulp sci-fi" style campaign, there can easily be exceptions within any given universe. If most aliens are humanoid, there can also be xeno-exotic aliens. Likewise, if the universe is populated by bizarre, exotic aliens, there can be cases of localized panspermia (or "lost colony" scenarios) where there are a few humanoid aliens.

Humanoid, Near-Humans and Demi-Humans

Aliens that look like us! Sure some have elfin ears, spoon-indentations on their foreheads or green blood. Other than some niggling details, they are pretty much human, and more often than not they are sexually compatible. Their culture (though historically different) is easily put into human terms. Their technology, society and even language seem completely human (and easily translatable into English). In many sci-fi shows and books, the aliens even speak perfect English on first contact! Parallel evolution is truly an amazing thing.

Humanoid aliens are the easiest route to take for devising alien civilizations, and some say even a copout. This is the lowest factuality level, at the epitome of space opera and pulp fiction, yet still an extraordinary setting for conflict, epic adventure and exploration. If humans can commit war and genocide against each other over such minor differences as religion, ethnic race and greed, it is not so implausible to do so with a near-human alien species.

It is, however, possible to explain away the existence of humanoid aliens with the theory of panspermia. It can even be said that a precursor race once populated the galaxy, and we (along with other near-human races) are their descendants (or descendants of the slaves who overthrew them).

For a role-playing game, humanoid aliens are the best choice. Why? Have you ever tried to role-play a two-ton silicate-based methane slug? It is much easier to step into the shoes of an alien who.. well.. has shoes to step into.

Creature-Features

Second in popularity to humanoid aliens, "creature-feature" aliens are quite prominent in science fiction. Many such creatures are hybrids with the humanoid class, that is lizard-men, dog-men, plant-men, and any race with the -men suffix. Other such creature-feature aliens are species that resemble mutated or giant versions of other Earth life, such as Starship Troopers' bugs, giant slugs like Jabba the Hut, and other aliens that make you say "hey that looks like a...". Even if they don't look human, they look like something familiar.

Creature-feature aliens are a compromise between humanoid and exotic aliens. They are not so exotic that they can't be playable in a role playing game, but yet they are more scientifically plausible (assuming they are done *right*, avoiding the cliché bugmen).

Such aliens must also arise from panspermia, however, the stellar fertilization occurred at a microscopic level, delivered by comets to a hundred different worlds, rather than the active transplantation of an ancient precursor civilization.

Even creature-feature aliens must have a world, culture, society and even religions, myths and dreams. Their mentality may be terribly alien, though there could be underlying laws of sentience which help to make certain psychological traits universal; greed, fear, love, hate, etc.

It Came from Outer Space!

To the uninitiated of science fiction, the first image conjured by the words "space alien" may be a big green monster with big eyes, huge crab claws, two tails and a drooling tooth-laced mouth. Such space monsters are certainly "creature-feature" aliens, but they should not be considered for a serious hard sci-fi game. Many such monsters are reserved for pulp sci-fi, space opera and movies which can only be watched if shown on MST3K. However, "it came from outer space" monsters do have a place in many sci-fi games.

In a Buck Rogers / Flash Gordon style space adventure, most of the enemy aliens will be space monsters. Indeed, they will be semi-intelligent, perhaps even intelligent, but they do not need to be developed or though out the same way a more logical or "flushed out" alien civilization should be.

The xenomorph from the Aliens series is a contemporary example of an "it came from outer space" alien. However, the popularity of the series, the Alien became a flushed out, well-developed race. Thus, in such a campaign, the heroes might meet up with "just another space monster" only to discover it is the most terrifying nemesis the universe has ever seen.

Aliens of this type are not suited for PCs or even NPCs. They are just space monsters.

Xeno-Exotics

Few and far between in sci-fi are the truly alien aliens. They will have little to no similarity to anything on Earth, and will have utterly alien psychologies. Therefore, they cannot be used for PCs. This is not because they are too powerful or unbalanced, but it is very difficult to play something that things so alien to our own desires. Playing an elf is not too hard, since even elves have the same biological needs and psychological responses as a human. Even playing an android is possible because that is something a human can identify with. Playing a cloud of sentient neon gas.. well that is just too weird.

Xeno-exotics are best used as a distant alien force. They make good enemies in a space war and are extremely unpredictable due to their alien nature, making it difficult to predict their tactics without knowing their drives.

Xeno-exotics are also good for first encounters and deep space exploration adventures. Finding such an alien and searching them out can make for a colorful story.

Gods from the Stars

The ultimate xeno-exotics in sci-fi are entities of stellar magnitude. Massive energy beings, crystalline lattice entities, sentient planets or stars and aliens from other realities. Such beings are staggeringly old and have god-like intelligence. They are clearly unsuitable for PCs, but make for interesting and dangerous encounters.

Such beings need no stats or skills. The GM simply decides what the being wants to do, and it is done. Simple.

Making Aliens

Making an alien race is almost the same as making a character. Alien races have modifiers to their base stats, can have inherent Talents and psychological traits derived from character Complications such as intolerance or stubborn.

Aliens are built by a Darwinian process, where certain biological traits, systems and adaptations are selected. Each of these cost a number of Evolution Points (EP). Thus, simple creatures have low EP values, while complex life forms have high EP values.

By default, humans have 75 EP. In an all-human campaign, all of the characters have 75 EP, which has been pre-spent on the "human species" package.

Evolution Points

This is a measure of how evolved a life form is. Highly evolved races have traits that ensure their survival, and cost more EP. Lesser evolved traits, such as open circulatory system, cost little or no EP because they have little benefit.

It may be tempting to treat EP like any other cost system, such as Option Points (OP) or Improvement Points (IP), but this should not be the case. Aliens are balanced within their own race, thus they should not have to pay points to be one of their own.

In a multi-species campaign, races with higher EP than human may have to pay OP to cover the difference, while those with lower EP may get bonus points. Thus if an alien race has 100 EP and a PC wants to play one, it would cost him 25 of his starting OP.

If the GM allows the players to create their own race, he can simply state "do not exceed 75 EP". NPC aliens can have any EP value the GM deems fitting, and he need not tell the PCs this value. After all, it is a tricky matter to judge what species is evolutionarily superior to another. In fact, many interstellar wars have been triggered over just this.

Complications

Many alien species display psychological complications. For instance, Larry Niven's Puppeteer's had extreme Cowardice (-30 OP). Complications are measured in Option Points, but can be translated into EP. It is assumed Complications have a negative effect on evolution, therefore, any Psychological, Personality or Compulsive Behavior Complications subtract 1/2 their OP value from their species' EP. The Complication value is halved because it has less impact between actual members of the same species, thus it is not so much a character flaw as a racial trait.

For instance, if you were making the Puppeteer race, it would have the Personality trait of "constant extreme severe coward" which has an OP value of -30. This would be equal to -15 EP.

It is very common for aliens to have Social Complications such as Bad Reputation, Personal Habits (usually related to eating), Oppressed and often Outsider and Distinctive Features. However, these traits are only relevant outside their own culture. Therefore they cannot be applied to EP. Such traits get relegated to background information.

Another example, from Babylon 5 "most people are disgusted with the eating habits of the Pak'ma'ra", as they are carrion eaters. Therefore individual Pak'ma'ra *characters* will have the Disgusting Eating Habit Complication for 10 points. This is part of the character, not the species.

The Distinctive Features Complication bears special notice here. Among different species, *all* alien species have this trait. It is what makes them alien. Thus this Complication should only be a Complication where aliens are rare, hated or feared.

For another example, in Macross, the Zentraedi have odd skin tones, odd hair colors and slightly pointed ears even when micronized. Early in the saga (2009-2011) any Zentraedi on earth would have this Complication. However by the later parts of the story, after the Zentraedi are integrated into human culture and well known by all, the features are there but they no longer count as a Complication.

Humanity Points

Humanity is a measure of how humans can relate to one another, and can be deteriorated by cybernetics, mental illness and psychological trauma. In a campaign with aliens, who are not human, they would natively have 0 Humanity, as they are not from human culture. Thus every non-human alien, by the rules, would be a raving psychopath bent on killing squishies. Clearly this is silly and needs to be handled differently.

In a campaign with aliens, the Humanity trait should be renamed Mental Stability. This assumes all sentient life has some basic pattern or Law of Sentience, which governs the sanity and psychological stability of all races. In essence, Mental Stability is identical to Humanity, except that it discards the "racist" term.

Cultural Interaction

The trickiest topic is cultural interaction between alien species. For the most part, this is race specific, and should be established by the GM. For instance, if a race is extremely xenophobic and intolerant of other races, they will have a great deal of difficulty interacting with others. On the other hand, dealing with a race of pansexual hedonists would suffer little more than some utterances of "oh my.." and lots of clothes being shed.

Depending on the race, its similarity to other races, its general attitude and true "alienness", the penalty will vary. Therefore it is necessary to gauges the Presence penalty based on these factors. Here are some likely modifiers:

Relation	Penalty
Culture only	-1
Somewhat alien	-2
Very alien	-4
Radically alien	-6
Completely alien	-8
Wait, what?	-10

Psychology	Modifier
Culturally adaptable	x0.5
Neutral	x1.0
Xenophobic	x2.0

For example, two near-human alien cultures which developed independently for the past 10,000 years on different worlds would have a -1 penalty to PRE rolls when interacting with each other. If a human met with a different humanoid alien, say a Perytonian from Robotech, they would suffer a -2 PRE penalty with each other. Likewise, two radically different xenophobic races interacting would suffer a -12 PRE penalty.

Creating Alien Races

Finally, the part you have been waiting for. You have in mind the alien civilization, their history and culture, and maybe a drawing of what they look like. So let's make an alien. This system only concerns itself with the biological aspects of the alien itself, and has nothing to do with their culture or psychology.

Creating aliens is broken down into ten systems: Form, Physical Exterior, Cardiovascular System, Respiratory System Bio-Stats, Locomotion, Feeding, Sensory and Communications, Neurological System, and Special Adaptations. Not all systems are essential for a race to survive, but in many cases EP is astronomical for such a *lack* of a system. For instance it costs 20 EP *not* to have a respiratory system, which is actually a huge evolutionary advantage not needing to breathe.

As a general rule, all aliens *must* have the following: form (formless counts as a form), cardiovascular system, respiratory system, bio-stats, feeding method and neurological system. Special adaptations include evolutionary advantages as well as "super powers" such as psionics or magic.

In Form, the size (relative to human) should be selected from between 30kg to 300kg. This is to keep alien creation as level as possible. Once the alien is completed, it may be scaled up or down as a Mekton. This is done last, as the scaling modifier affects the final EP of the race.

Example Alien

Below is a standard Earth human. This can be used as a guideline and as a template to quickly alter into other humanoid races. Extra cosmetic features such as "bald with bone crest on the back of the head" or "pointed ears" are cosmetic effects with no EP cost.

Race: Human Being
    Native Designation: Homo Sapiens Sapien
    Homeworld: Earth (aka Terra)
Form: Multi-cellular Carbon-based, 80kg average [4 EP]
Physical Exterior: Skin with hair follicles [1 EP]
Cardiovascular: Close centralized, 1 heart [5 EP]
Fluid Type: Warm blooded [4 EP]
Respiratory: Air lungs, hold breath 5 minutes average [6 EP]
Lifespan: 60 year unaugmented [12 EP]
Sleep Time: 30% of the time [5 EP]
Vulnerabilities:
    Radiation, Extreme, Stunning [-4 EP]
    Vacuum, Strong, Killing [-5 EP]
Immunities
    G-Forces: 8G [4 EP]
Locomotion
    Biped Lateral Walker [4 EP]
    Partial Swim [2 EP]
Feeding: Omnivore [4 EP]
Sensory
    Sight, Optical [4 EP]
    Smell [3 EP]
    Taste [2 EP]
    Touch, Direct [2 EP]
    Hearing, Sonic [3 EP]
Communication

Vocal Communication, Sonic [2 EP]
Body Communication [1 EP]
Neurological: Neuro-Electrochemical, Centralized [5 EP]
Special Features
Secondary Limbs, 1 pair [4 EP]
Fine Manipulators (both hands) [6 EP]
Vestige Manipulators (both feet) [0 EP]
Vestige Tail [0 EP
Crushing Jaw [1 EP]
Racial Complications: none racially
Scale: x1 (human)
Total Cost: 75 EP
OP Cost: --

Form

All alien races must have a form. This determines the alien's biochemistry, structure and physical properties. Even if an alien is formless, that is its form.

Proto-cellular Carbon Based [1 EP]

Carbon based biochemical structures, lacking unified cellular organization. Primarily reserved for single-cell organisms. However, large, macro-scale organisms could display proto-cellular organization. Most shapeshifters should be proto-cellular. Requires water and basic carbon based cellular nutrients to support life. Environmental tolerance requires either oxygen or CO_2 for reparations, temperature range from between -10 to 40 C (at extremes). High intolerance to radiation and violently reactive chemicals. A Physical Exterior must be chosen, and it must be carbon based.

Multi-cellular Carbon Based [4 EP]

A multi-cellular carbon based form is typical of most Earth and Earth-like creatures. All biological systems are comprised of specialized groups of microscopic cells, clustered to form organs and internal structures that are the mechanisms of life. Requires water and basic carbon based cellular nutrients to support life. Basic chemical and biological structure is controlled by DNA. Environmental tolerance requires either oxygen or CO_2 for reparation, temperature range from -10 to 40 C (at extremes). High intolerance to radiation and violently reactive chemicals. A Physical Exterior must be chosen, and it must be carbon based.

Multi-cellular Silicate Based [5 EP]

Similar to carbon based, except silicon is a primary base element. Cells are comprised of silicon crystal structures, but water is still essential. Growth of biochemical structures governed by a crystalline form of DNA. Silicon based organs, structures and silicate chemical reactions are the mechanism of life. It does require water and basic silicate nutrients. Environmental tolerance requires either oxygen or methane for reparation, temperature range from -30 to 50 C (at extremes). High intolerance to radiation and violently reactive chemicals. A Physical Exterior must be chosen, and it must be silicon based.

Silicon Crystalline [8 EP]

A silicon crystalline form is a complex structure organized in the form of silicon based crystals. There are no cells, rather, the life form's existence is based purely on the

dynamics of the energy and growth patterns of the silicon crystals. Unlike non-living crystals, a silicon crystal life form has a crystal-morphic body; that is, it can shape and reform its crystals, allowing for a wide range of mobility, growth, and adaptation seen in carbon based life forms. A silicon crystalline life form does not require water. However, it does require an abundant source of energy, typically in the form of solar radiation (Feeding type is Solar Energy). Energy distribution can be chemically induced (select Osmosis Circulatory System). Other requirements should be similarly selected. Temperature range from -30 to 50 C (at extremes). High intolerance to radiation and violently reactive chemicals. A Physical Exterior must be chosen, and it must be silicon based.

Silicon Non-Crystalline [8 EP]

Essentially this is a living rock. Amorphic mineral patterns within the non-crystalline silicon stone form the energy conductive pathways for the basis of the being's brain (Neurological System type is electrical semiconductor). Most rock beings lack limbs and mobility. However, "golem"-like silicon rock creatures are possible with the addition of limbs and mobility. Temperature range from -30 to 50 C (at extremes). High intolerance to radiation and violently reactive chemicals. A Physical Exterior is unnecessary, but may be taken. Scaled up to Excessive scale, this might represent a sentient planet.

Metallic Crystalline [10 EP]

Such life is comprised of metallic compounds, crystals and often silicon as well. These are not robots or machines, they are naturally evolved on worlds of metallic crystal life. A metallic crystalline life form does not require water (and should actually avoid it). An abundant supply of energy is needed, with any conceivable feeding method (Carnivorous in this case would be eating metals). Respiratory and Circulatory systems can be taken or select None. Temperature range from -40 to 60 C (at extremes). Most do not fare well in water (rusting), and it may be vulnerable to other things such as radiation, energy spikes, electricity, etc. Physical Exterior is unnecessary but may be taken.

Mechanical - Artificial [10 EP]

This is a robot. Realistically such a life form should be built using Mekton mecha rules and scaled down as appropriate. If the GM really wants to use this system for making a robotic or cybernetic race, treat them as Metallic Crystalline above, except that they are, in fact, machines and not crystalline.

Gaseous [15 EP]

The life form's body is made up of chemically active gasses clustered into a cohesive cloud (typically colored or even glowing). Generally, the "gas" is simply billions of complex molecules interacting with one another. A gaseous being can float, but will drift aimlessly with the wind unless some kind of locomotion is taken (Glide or Air Jet are most appropriate). Feeding method is usually solar, and many gaseous beings require respiration of some sort of reactive gas (oxygen, hydrogen, chlorine, etc). Circulation should be Osmosis. No Physical Exterior is needed.

Liquid [20 EP]

This life form has a gelatinous or cohesive body of chemical liquid. This liquid is usually made of organic compounds, perhaps hydrocarbons, but can also be a silicate compound. Fully swim or slither (or both) is most appropriate for locomotion. Circulation should be Osmosis. No Physical Exterior is needed.

Sonic Resonance [30 EP]

This life form does not exist within a physical body, rather, it resides in a conscious pattern of sonic vibration, resonating through the molecules in the air or other nearby matter. It must obtain energy to maintain its resonance, or it will fade away and vanish. It is impervious to kinetic damage, but energy does normal damage. Sonic attacks can disrupt and even kill such a being. It will die if exposed to a vacuum where sound cannot exist. This is an extremely exotic form, the precise nature of which should be determined by the GM. No Physical Exterior needed.

Pure Energy [40 EP]

Patterns of energy comprise the form and consciousness of this life form. The energy can be any form; light, radiation, magnetic, electrical, thermal, atomic (fusion/fission), quantum or whatever. The being's body is of pure energy, so it will not have physical traits. Neurological system should be Superconductive. Energy beings are impervious to physical attacks, but energy attacks inflict normal damage. This is an extremely exotic form, the precise nature of which should be determined by the GM. No Physical Exterior needed.

Space-Time Structure Matrix [50 EP]

Beyond pure energy are conscious beings that exist within the folds and patterns of space-time itself. Where space can warp, bend and crumple, a powerful space-time "matrix" can form into a crystal-like pattern. This patter, like all patterns, can conceivably develop self-awareness. This is an extremely exotic form, the precise nature of which should be determined by the GM. No Physical Exterior needed.

Physical Exterior

All physical beings must have a physical exterior. Unless the form selected states one is unnecessary, pick one from below.

Skin [1 EP]

If a race has nothing else, it must take skin. In most cases, skin will have some hair follicles, but not enough to count as fur.

Fur [2 EP]

The species has a layer of fur. Such a being automatically has skin as above and need not buy it again. Primarily, this exterior helps in keeping warm in cold environments. Fur may be taken in addition to other exteriors, such as shell or exoskeleton.

Scales [5 EP]

Common among reptile races. The scales are tough enough to provide +5 KD (5 SP against killing damage).

Feathers [4 EP]

All bird races should have this, although some dinosaur-like species may have this as well. Feathers provide +2 MA to flight.

Shell [5 EP]

Common among shellfish and mollusks, and some dinosaurs. This provides +15 KD (15 SP against killing damage). Due to the restricted mobility, the species has -1 AGIL.

Exoskeleton [10 EP]

This type is found on all insects and crustaceans. It provides +10 KD (10 SP against killing damage), but because it is fully articulated there is no penalty.

Cardiovascular Systems

This is how nutrients are transported through the species' body and how waste is removed. In some cases, this is not "cardiovascular" at all, but this category is the best descriptor for it. All races must select this category, even if None is chosen. Both the system and the fluid must be picked.

Open Centralized Circulatory System [-10 EP]

This is a very primitive system where blood is pumped into a lung or gill, then into a cavity where it is absorbed by surrounding tissues, then pumped back out. This makes the species very fragile (-2 BOD).

Closed Centralized Circulatory System [5 EP]

This is the normal system found on most animals; consisting of a heart and vessels. Some may have multiple hearts, helping ensure that if one is damaged that the being can continue survival. Each additional heart costs +3 EP and adds +2 Hits to the torso/pool up to a maximum of +6 for a total of four hearts.

Closed Decentralized Circulatory System [12 EP]

Same as closed centralized, however there is no central pumping organ. Muscles in the body pump the blood to the organs. The effect is that there is no central heart to damage. The being gains +5 hits to the torso/pool.

Osmosis Circulation [15 EP]

This can be considered open decentralized circulatory system, but is far more advanced than any other circulation system. This should be used to describe highly exotic forms of circulation, where energy, light, radiation or other forms of nutrient circulation is necessary. Basically, the fluid (or nutrient source) is simply filtered through the body.

None [30 EP]

This is for races with no circulatory system. Be sure you understand what this means before you select it. In most cases, Osmosis should be taken. Even if the being is pure energy, it must circulate fresh energy and expel waste heat somehow, and this is usually Osmosis. Machines would use closed decentralized circulatory system, conveying electrons through circuitry.

Cold Blooded [2 EP]

Such beings are at the mercy of the environment. When it gets too cold, they slow down. When it gets too hot, they also slow down. At the extremes, they will die. Only at certain temperatures are they at peak performance.

Temp	*Modifiers*	
0-10 C	REF/MA/SPD x0.2	-5
11-20 C	REF/MA/SPD x0.5	-3
20-25 C	REF/MA/SPD x0.75	-1
25-30 C	REF/MA/SPD x1.0	+0
31-35 C	REF/MA/SPD x1.2	+2
36-40 C	REF/MA/SPD x1.0	+0
41-45 C	REF/MA/SPD x0.5	-3
46+ C	Death or Dying	

Warm Blooded [4 EP]

Such beings are able to sustain their body temperature despite the outside environment, to certain levels. Typical operating parameters are from -20 C to 40 C at the extremes.

Chlorophyll [2 EP]

Chlorophyll is a green organic compound comprised of oxygen, hydrogen, nitrogen, carbon and magnesium. It absorbs solar radiation, used for photosynthesis. You must have Feeding method Solar and take Absorption Respiration (CO or CO_2). Chlorophyll is usually circulated via closed decentralized circulatory system, as found in plants.

Oxygenated Hydrocarbons [5 EP]

Liquid hydrocarbon compounds that are oxygenated (or carrying CO_2) can be used to deliver oxygen and nutrients through a body. This may be found in multi-cellualr carbon based aliens. Hydrocarbons should be used on races in an Earthlike environment. Chlorofluorocarbons and Chlorofluoromethane are similar, though more exotic, derivatives of this. Chlorofluorocarbons can carry O_2 or CO_2, but work at low temperatures (below freezing) allowing for a temperature range of -50 C to 0 C. Chlorofluoromethane works at even lower temperatures where CO_2 is frozen, so methane is the choice chemical for respiration (that is, methane breathers use Chlorofluoromethane for circulation).

Acidic Chemicals [4 EP]

The race has acid for blood. This usually implies a highly exotic environment (such as a sulfuric acid atmosphere), but can also evolve in an Earthlike world (in which case oxygen is delivered by chemical reaction through the body). Such a race is usually impervious to acid itself. By default, the acid is not dangerous or corrosive. It costs +1 EP for every 1d6 Hits the acid blood can inflict, up to a maximum of 10d6 for compounds such as hydrofluoric acid or aqua regia.

Exotic Chemical [4 EP]

Other chemicals could also transport oxygen, CO_2, methane, chlorine, fluorine and other highly exotic gasses and nutrients. This is up to the GM. If the chemicals can inflict damage like acid, this costs +1 EP per 1d6 damage up to 10d6.

Energy [5 EP]

Energy is the "fluid" of circulation, be it thermal, electrical, light or whatever. Usually this is reserved for crystalline, silicate, energy or mechanical beings, and works in conjunction with Osmosis or closed decentralized circulatory systems.

Respiratory System

Most races need to breathe a gas of some sort. When picking a respiratory system, the GM should indicate what gas or gasses the species inhales and what they exhale. No respiratory system should be picked if the species has no circulatory system. Multiple respiratory systems may be selected, such as amphibious creatures.

Absorption [1 EP]

The species absorbs gasses directly through its skin. Due to the fragile nature of races with this, they suffer a -1 penalty to BOD. It should be specified whether this works in air or water. It costs 2 EP for it to work in both.

Water Gills [2 EP]

Gills are external structures filled with gas absorbing tissue. Gills are vulnerable to direct attack (x1.5 damage but -4 called shot).

Water Lungs [3 EP]

Basically the same as water gills, except they are fully internal. These are found in higher evolved non-terrestrial aquatic life forms.

Air Gills [2 EP]

This is a primitive oxygen extraction system, usually in the form of feathery fans or fleshy external frills that absorb gasses. Gills are vulnerable to direct attack (x1.5 damage but -4 called shot).

Air Lungs [5 EP]

These are fully internal gas absorbing organs used for respiration (most Earth land animals use these).

Hold Breath [1 EP per 5 minutes]

This may be taken with any of the above systems. It is assumed most average beings can safely hold their breath for up to 1 minute. Each EP spent on this increases the safe time by 5 minutes. Earth whales can typically hold their breath for up to 30 minutes, sometimes more.

No Respiration [15 EP]

This is for species that don't need to breathe at all. Such beings extract needed gasses from chemical synthesis and highly advanced anaerobic metabolic regulation.

Bio-Stats

This is a collection of non-related biological traits.

Life Span [1 EP per 5 years]

All races have a life span, even if that is rated in millennia. The average human life span, un-augmented by medical/cybernetic technology, is approximately 60 years, which is 12 EP.

Un-Aging [5 EP]

This option is added to life span above. The species in question does not appear to age past full maturity (20-25 years as a human). The race is not immortal, simply they do not age, and will simply die (with a young corpse) at the end of their life span.

Immortal [40 EP]

Instead of choosing a life span, this race does not age and can live eternally, barring death from violence or accident.

Sleep Time [variable EP]

Most races require down time to rest and recover fatigue, heal and allow their brains to refresh. This is accomplished through sleep. This "sleep" time can also represent meditation, lucid dreaming or any other process so long as the being is "incapacitated" during the rest period. The EP cost is based on the % of a 24-hour day (or % of however long their planet's day is) that they require rest. For reference, humans need 30% of their day for sleep (7 hours).

Sleep	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
EP	-1	0	1	2	3	4	5	6	8	10

Vulnerabilities

These are evolutionary flaws. They might be caused by a lack of a substance on their homeworld (such as UV rays), and when exposed to such, members of that race have no protection and suffer damage. The range of vulnerabilities are as infinite as the number of substances and forms of energy in the universe, thus they can't *all* be listed. The following will cover some of the most common ones.

Three things must be considered when choosing vulnerabilities. First is how common the substance is to the campaign (not their homeworld). Second is how much damage it does. Third is whether this damage is stunning or killing damage.

For example; radiation is extremely common in space, though earth is protected. Thus humans require radiation protection on spacecraft and space stations. If exposed to radiation, we take damage.

While it might be tempting to list out every possible vulnerability a race might have, such as water/drowning, only 2-3 major ones should be listed.

Frequency	*Value*	*Examples*
Very Rare	1	exotic matter, dark matter, anti-matter
Rare	2	rare element, exotic chemical
Unusual	3	radiation, chemical, vacuum
Common	4	metal, plastic, noise
Very Common	5	light, oxygen, water, salt
Intensity	*Value*	*Damage*
Mild	1	1d6 per turn
Strong	2	2d6 per turn
Severe	3	3d6 per turn
Extreme	5	5d6 per turn
Damage Type	*Modifier*	
Mental	/5	
Stun	/2	
Killing	x1	

Mental damage is essentially a psychological phobia and "damages" the being's Mental Stability, which recovers at a rate of 1 per minute away from the source. Most vulnerabilities are actually stun damage.

Example; humans have a vulnerability to intense radiation. Damage is extreme, but is only stun damage. This has a value of (3 +5) = 8 /2 = 4; thus humans get 4 EP back.

Immunities

These are the opposite of vulnerabilities. They make a race immune to something that usually does damage. You cannot have an immunity to something you have a vulnerability to. The EP is only half if the immunity only protects from stun damage. The list can be expanded by the GM as needed.

Type	*EP*
G-Force (per 2G)	1
Disease (per type)	2
All Diseases	15
Poison (per type)	2
All Poisons	15

Acid	10	
Fire/Heat	10	
Electricity	15	
Ranged Physical	25	
Melee Physical	20	
Unarmed Physical	20	
Sonic	15	
Light/Laser	20	
Other Energy Type	20	(ion, particle beam, plasma, etc)

For example; Total immunity to kinetic damage can be accomplished by combining Ranged, Melee and Unarmed for 65 EP. Total immunity to energy would be covered by combining Fire/Heat, Light/Laser, Sonic and Other Energy if applicable for 60 EP.

Immunities are rare, and there should be an evolutionary explanation for having one. Having immunity to Heat/Fire may arise from evolving on a hot, volcanic planet. Most immunities will be Disease, Poison, Acid and Electricity; the rest are more comic book superhero than realistic.

Locomotion

If a species is to be mobile, it must have some form of locomotion. Many races have more than one form of locomotion. Humans have Biped (lateral walker) and partial Swim, while birds have Winged Flight and Biped (lateral jumper), and flying fish have full Swimming and Glide Flight.

None [0 EP]

The species can't move and has 0 MA.

Full Swimming [4 EP]

The race is designed for swimming in water or other liquid. Members will have fins and are aquadynamic. They have 2x MA swim speed.

Partial Swimming [2 EP]

The race isn't designed to swim, but has a form of locomotion that allows them to swim, such as arms and legs that allow swimming. They have 1x MA swim speed.

Winged Flight [5 EP]

The race has wings of some sort, which flap and allow them to fly without restriction up to 1000m attitude. They have 3x MA flight speed. It costs +2 EP if the race can hover.

Glide Flight [3 EP]

The race has wings of some sort, but they can only use them to glide. They may glide down or catch upward air currents, and it has to jump off higher levels to achieve flight. They have 2x MA flight speed. Such beings will drop 2m per turn unless they catch upward air currents.

Gas Bag Flight [1 EP]

The race has a large bag of hydrogen gas to support them on the air (hydrogen because helium is impossible to form biologically). This race is very slow and normally floats with the wind. Most will have fleshy fins or sails for maneuvering. They have 1x MA flight speed. Air jets or winged flight could be used to make it fly faster. The gasbag is very vulnerable to explosions, and lightning is the major killer of such beings.

Jelly Bag Swimming [1 EP]

This is a bag of jelly material in the form of a bubble (like a jellyfish). It allows for floatation in water, either on the surface or underwater. Aqua jets or Full Swimming must be taken for it to move on its own.

Aqua Jets [5 EP]

This is a water propulsion system seen on squid, octopi and jellyfish. Water is sucked in and jetted out the back, causing the creature to thrust forward. They have 3x MA swim speed. If jelly bag swimming is also taken, the creature will not sink while resting.

Air Jets [8 EP]

This is basically a turbo fan for flying creatures. Instead of winged or glide flight, this race has a jet-like "engine" which sucks in air, then shoves it out at a faster rate, using muscles or a biological equivalent of a turbo fan. They have 5x MA flight move. Hover costs +2 EP.

Slither [2 EP]

This is the motive system of snakes, snails and slugs. They have 0.5x MA move speed.

Monoped [3 EP]

This race moves by hopping on a single large leg. In most cases, the single leg seems to have evolved from two legs that grew together. It cannot walk and can only jump. They have 2x MA Leap.

Biped (Lateral Walker) [4 EP]

Typical for most bilateral bipedal races such as humans. Two legs, with the ability to walk, run or jump. Movement is as per the basebook.

Biped (Lateral Jumper) [3 EP]

This is a two legged jumper, like a kangaroo. It cannot walk, only jump. They have 2x MA for Leap.

Biped (Linear Walker) [4 EP]

This is basically an evolved quadruped whose legs grew together to form two legs, one in front and one in back. The creature is less stable but more agile. They have x2 MA move, x4 MA run and x0.5 MA leap. They can only jump sideways.

Quadruped [4 EP]

The race has four legs, making them fast and good jumpers. They have x3 MA move, x4 MA run and x1 MA leap.

n-taped [4+ EP]

This is a creature with any number of evenly paired legs above four. Base speeds are the same as quadruped. Each additional pair of legs beyond 3 pairs is +2 EP and will increase move, run or leap (chosen when selected) by +x1.

Feeding Method

Unless the race does not require food or liquid, all races must have a feeding method. The precise nature of its diet should be determined, based on the feeding method and its homeworld's environment.

For instance, a carnivore evolved on a silicone-based life planet would only be able to eat "silicate-meat", and would not be a flesh-eating space monster.

Rarely ever should food or life forms from another planet be digestible, and may even be highly toxic. Humans, for instance, would not be able to eat biomaterial native to other worlds, unless an extremely cinematic view is taken.

Herbivore [1 EP]

This race eats plant material, or the equivalent on their world. Plants should be plentiful, however, they are not very filling. Large herbivores must eat almost constantly.

Carnivore [3 EP]

This race eats meat and fleshy material, or the equivalent on their world. It must hunt to find food, or if developed, operate farms and breed livestock. Most carnivores are satisfied with one large meal per day.

Scavenger [2 EP]

This race can eat any sort of dead or partially decayed material. It does not hunt, rather it scavenges. A civilized scavenger society may have strict religious laws on how long the food must be dead before it can be eaten.

Omnivore [4 EP]

This race can eat both meat and plant material (+2 EP if they can scavenge). Normally a few small meals or one large meal per day is enough.

Liquivore [2 EP]

This race feeds on liquids. The exact method is up to the creator. This can be like vampire bats or spiders, or injecting digestive juice into a victim and slurping the broken down matter out like many insects.

Parasite [0 EP]

This race must latch onto another organism and live off the host's metabolism like chiggers and tapeworms. Without a host, the parasite dies.

Solar Energy [1/3/6/9 EP]

This race absorbs solar energy. This can be used for plants, or races that use photoelectric or other solar powered chemical processes. The EP cost is based on the level of need.

EP	*Requirement*
1	Constant exposure
3	Half of a day exposure (typical)
6	Quarter of a day exposure
9	One hour exposure per day

Thermal Energy [3 EP]

Many bacterial and worms flourish on the deep-sea thermal vents on Earth's oceans. Such a feeding method could exist with alien races. Hot thermal energy is used to cause the chemical reactions that sustain life. Sulfur-based metabolism often fits well with this type.

None [15 EP]

The race does not require food or water or energy intake. This is generally unavailable, but some extremely evolved entities may have this ability.

Sensory and Communication

In order to perceive and react with the environment, all creatures must have some form of sensory input. The lack of sensory input affects the Perception checks of the race. For instance, lacking sight might increase hearing and scent. This is not a handicap,

rather, it is how the race evolved. The race's history, culture, language and technology must reflect their senses, or lack thereof.

Sight, Optical Spectrum [4 EP]

This is basic sight as humans perceive it. Sight is normally through "eyes" similar to those of mammals or insects. Many exo-biologists believe that eyes are a "universal trait" found on all life on all planets, as they have evolved more-or-less the same on thousands of completely different Earth life forms. The cost is reduced by -2 EP if the race is colorblind, and increased by +2 EP if the race has Nightvision.

Sight, Infrared Spectrum [6 EP]

This is sight in the low red to infrared range. It allows the race to see primarily in heat, making it less susceptible to the penalties of darkness. This may evolve on races which life is underground or on planets with such dim stars that they live on "twilight worlds".

Sight, Radio Wave [8 EP]

Radio wave sight organs must be quite large, usually in the form of long antenna or "fan" of connected antennae (for parabolic radio reception). This only allows the race to see radio waves, not interpret them as a radio message (unless it is blinking in a language they can understand, like Morse Code). However, races with Radio Communication must take this (or Radio Hearing) to receive messages.

Sight, Ultraviolet Spectrum [6 EP]

This is a form of sight that uses the ultraviolet portion of the EM spectrum. This may evolve on worlds where a great deal of UV radiation penetrates the atmosphere. Alternatively, the race may have UV "flashlight" organs to illuminate their surroundings for +1 EP.

Smell [3 EP]

This sense works by taking in a sample of air and tasting it with specialized organs or tissues, which determine the chemicals and particles in the air. Signals are then sent to the brain for interpretation.

Taste [2 EP]

Taste evolved from the same system as Smell, and generally the two are linked. Taste is much more acute, but localized to food or items placed in the mouth. This can help determine the quality of the food and if it is edible or poisonous. For taste sensors on the outside, such as on the hands or feelers, this costs +1 EP.

Touch, Direct [2 EP]

Sensors throughout the skin are able to detect pressure, damage (pain), heat/cold and other similar sensations.

Touch, Ranged [6 EP]

Basically the same as touch, but works at range. It is used to feel pressure changes and movement at long range. Sharks and other super-predators often have this ability.

Hearing, Sonic [3 EP]

Sonic hearing is the sound perception sense familiar to humans and most Earth animals. Hearing is usually parabolic, enabling the race to determine the source of the sound.

Hearing, Subsonic [3 EP]

This is hearing in the range below what humans can hear. Races with this ability often communicate in subsonic ranges as well.

Hearing, Ultrasonic [3 EP]

This is hearing in the range above what humans can hear. Races with this ability often communicate in ultrasonic ranges as well.

Hearing, Radio [5 EP]

This is hearing in the radio wave band of the EM spectrum. Races with radio hearing can pick up radio waves, although they may not be able to interpret them. Species that communicate via radio waves may use something similar to Morse Code or a more complex form of wavering radio squeaks and whines. Races with Radio Communication must take this (or Radio Sight), to receive the radio message.

Sonar [5 EP]

This race sees by sending out subsonic pings to roughly image its surroundings. This works in either water or air, but not both. For both, this system must be purchased twice.

Radar [8 EP]

This race sees by sending out pulses of electromagnetic radiation, and receives the reflection to image its surroundings. This is effective only in the air, but has a much longer range and generates a crisper images than sonar can.

Electromagnetic Sense [5 EP]

This is basically the ability to sense the polarization of strong EM fields, such as a planetary magnetic field. This is only used as a navigation aid and is found on most flying animals. It gives a +1 bonus to Navigation, and may have other benefits.

Electromagnetic Imaging [8 EP]

This race can see electromagnetic fields created by magnets, electronics and even natural brainwave patterns. It can sense anything electrical, neuro-electrical, metallic or magnetized.

Antenna [+2 EP per sense]

This is a set of sensory antenna which assist in sensing the environment through subtle odors, shifts in the air and direct contact. Any sensory system enhanced by antenna gain a +1 bonus to Perception checks.

Acute Sense [+3 EP per sense]

As per the Perk.

Enhanced Sense [+5 EP per sense]

Any of the above systems can be enhanced beyond that of just "acute". This grants a +3 bonus to Perception checks with that sense.

360-degree Sense [+3 EP per sense]

Any of the above senses can be augmented to cover a full 360 degree arc. Hearing and smell are automatically 360 degree senses for free.

Vocal Communication, Sonic [2 EP]

This is the form of communication used by most Earth creatures. It is required that the race has Hearing, Sonic to receive such communication.

Vocal Communication, Subsonic [3 EP]

As per Vocal Communication, Sonic except that the race's noise is in the subsonic range. It is required that the race has Hearing, Subsonic to receive such communication.

Vocal Communication, Ultrasonic [3 EP]

As per Vocal Communication, Sonic except that the race's noise is in the ultrasonic range. It is required that the race has Hearing, Ultrasonic to receive such communication.

Chemical Communication [1 EP]

This is a fairly short-ranged (perhaps touch only) form of communication. It is accomplished by sending chemical signals in the form of odors of pheromones to other members of its race. Range is limited to a maximum of 10m or less. Ants communicate in this manner. It is required that this race has the Smell sense, unless the range is Touch only, in which case it needs Taste or Smell. This can be boosted by Antenna.

Body Communication [1 EP]

Everyone knows what flipping the bird communicates. This form can be complicated sign language or a full body dance. Depending on the species' physiology, this can be a beautiful and exotic display to other races, even if they have no idea what is being communicated. It is required the race has some kind of sense to "see" the gestures.

Radio Communication [5 EP]

The race can communicate through naturally evolved radio transmission. This has extremely long range, and the airwaves around communities are filled with radio chatter. Individuals may have their own unique frequency, or the entire race may share the same one. Radio communication can come in two forms; Radio Sight or Radio Hearing, and requires the appropriate receiving sense.

Highly Exotic Communication [8 EP]

There are other, more exotic forms of communication that are possible. Such forms as tachyon, mental or psychic, intra-dimensional phase shifting or whatever. The race must have an appropriate sense to receive the communication.

Hive Mentality [5 EP]

Some races are members of a large hive whose mind is spread out among many individuals instead of just one. Usually this implies a shared or group memory, centralized command (queen) and various levels of hierarchy (workers, drones, breeders, etc). Exactly how this works is up to the creator, but generally Chemical, Radio or Exotic communication are the choices. It is unlikely such a race can be a PC unless it somehow breaks from the hive and has enough self-intelligence.

Neurological System

In Earth life, the neurological system encompasses the brain and nervous system. For alien races, this could be semi or super conductive circuitry, intra-cellular communication or or other signal carrying methods. Current exo-biology studies show that neurosystems similar (at least in form) to those on earth may be a universal trait, as there are no successful examples of an alternate system. Even computer processing can be considered a primitive artificial neurological system.

Neuro-Electrochemical, Centralized [5 EP]

This is the basic neurological system for all Earth life-forms. Chemical singles are passed through nerves, special cells designed to quickly processes information, and transport the singles to a central cluster of highly interconnected neurons. These neurons communicate in a complex matrix of electrochemical signals, which translates to nothing less than the equivalent of sentient bio-computer. Damage to the central processing center

(the brain) is can cause extreme critical damage. This is the base, default neurosystem, and there are no characteristic modifiers for taking it.

Neuro-Electrochemical, Distributed [5 EP]

Similar to above, however, there is no central processing center. Thought and memory are distributed through the neural system of the entire body. It is impossible to make a direct hit on the brain. On the down side, severe injury to any part of the body can cause mental trauma or memory lose. Because of the distribution, thinking tends to be slower, but reflexes are somewhat enhanced. This grants +1 AGIL but -1 INT.

Biochemical, Centralized [-5 EP]

There is no real nervous system, rather, each cell communicates directly with the cells beside it, passing information by chemical osmosis. There is a central processing center, a group of specialized cells with a high level of interconnectivity and rapid chemical processing capability. Damage to the central processing center (the brain) is can cause extreme critical damage. This system is much slower and more primitive than Neuro-Electrochemical. It incurs -1 INT and -1 AGIL. This *gives back* 5 EP.

Biochemical, Distributed [0 EP]

Similar to above, but there is no need for a central processing center. Thought and memory are distributed on a cellular basis, with each cell performing a small portion of the brain function. It is impossible to make a direct hit on the brain. On the down side, severe injury to any part of the body can cause mental trauma or memory lose. Thinking and memory recall is not improved, but the added distribution helps alleviate the reflex impediment by giving a quicker reaction time. This system only incurs a -1 INT.

Semiconductive, Centralized [10 EP]

This may be in the form of crystalline-metallic conduction, or a naturally evolved silicon-based neural network. Whatever the case, thought and memory are processed by electrical impulses carried through semiconductor material. Signals are carried through the body in a similar fashion. Damage to the central processing center (the brain) is can cause extreme critical damage. This should be the default system for all silicon-based life-forms. This system works faster and better than neuro-electrochemical, giving a +1 INT and +1 AGIL.

Semiconductive, Distributed [15 EP]

Similar to above, but there is no central processing center. Thought and memory are distributed through the entire system, much like a network of billions of processing nodes. It is impossible to make a direct hit on the brain. On the down side, severe injury to any part of the body can cause mental trauma or memory lose. Thinking and memory recall is not improved, but the added distribution allows for faster reflexes. This grants a +1 INT and +2 AGIL.

Superconductive, Centralized [20 EP]

Similar to semiconductive, however, the signals are carried on superconductive material. This may be optical, or it may be superconductive electrical. Such as system would be possible on a race native to an extremely cold environment (such as a crystalline being on a frozen methane world), or other such exotic life forms. Because it can think and react so fast, this grants +2 INT, +2 AGIL.

Superconductive, Distributed [25 EP]

Similar to above, but there is no central processing center. Thought and memory are distributed through the entire system, much like a network of billions of processing

nodes. It is impossible to make a direct hit on the brain. On the down side, severe injury to any part of the body can cause mental trauma or memory lose. This is the default system for energy beings, sentient worlds and stars, and other such super-entities where thought and memory are processed by quantum weirdness, psionics, or just plain magic. This system grants +3 INT and +2 AGIL.

Blind Reaction [+2 EP]

Members of this race can counterstrike with no negative modifiers for darkness in hand-to-hand, even if they can't see their opponent.

Combat Sense [+2 EP/Level]

Members of this race automatically react faster to danger. For every level taken (up to 5), this race gains a +1 to Initiative rolls in combat.

Eidetic Memory [+2 EP]

Members of this race can never forget anything, and can easily recall memories and information.

Lightening Calculator [+2 EP]

Members of this race can automatically perform complex mathematics operations without
using aids.

Common Sense [+2 EP]

This race has the Common Sense Talent.

Intuition [+2 EP]

Members of this race have an uncanny feel for hunches, as per Intuition Talent.

Direction Sense [+2 EP]

Members of this race never get lost; they always know there they are and can orient without external clues.

Time Sense [+2 EP]

Members of this race always know what time it is and how much time has elapsed between the present and the last time you checked.

Special Features

Stuff to customize your alien race.

Secondary Limbs [variable EP]

Most races that have limbs have only legs. These are covered in the Locomotion section. However, many sentient life-forms have arms as well. It costs 4 EP points to have *one* pair of arms. It cost +5 EP each additional pair of arms (higher cost because it is so rare). Such limbs may be used to grasp, strike, and hold things. Fine manipulators may be added (long fingers and an opposable thumb), otherwise the limb is not automatically capable of fine manipulation. Vestige Limbs are limbs that have atrophied over the course of evolution. These may still have a slight value, able to move a bit, and perhaps hold a very small or light object. A vestige limb only costs 1 EP per pair, and should have little use. Ambidexterity costs +2 EP per pair of limbs. Double-Jointed also costs +2 EP per pair of limbs.

Tentacles [4 EP per pair]

Many alien races seem to have tentacles. These are like limbs, but far more flexible. Tentacles are basically the same as limbs (that is, they can grasp, strike, and hold), however, they *cannot* have fine manipulators. On the other hand, tentacles are far

more flexible than normal limbs, with an amazing degree of motion and grasping capability. Of then, this flexibility can more than make up for a lack of fingers or thumbs. Each *pair* of tentacles cost 4 EP. Some races have only one tentacle (a trunk) and this cost just 2 EP. To have four pairs of tentacles (eight tentacles) would cost 12 EP. A tentacle can do striking damage equal to normal punching damage of the same Strength. Vestige tentacles are called Tendrils, see below.

Tendrils [1 EP per pair]

Do not mistaken tendrils with tentacles. Tendrils are smaller miniature tentacle-like structures. They serve little practical functions, are often evolutionary leftovers from gills, swimming fins, or other such structures. Tendrils may hang down from the face, and serve as "lips" or food-shoveling organs, which help in eating.

Fine Manipulators [3 EP per limb]

Fine manipulators are those such as fingers, thumbs, or something equivalent. They enable delicate or fine manipulation of small object, tools, buttons, and other such abilities familiar to us all. It cost 3 EP per limb, therefore, to give fine manipulators on both limbs would cost 6 EP. Vestige manipulators are fine manipulators that have atrophied over the course of evolution. On humans, the toes of our feet have become vestige manipulators. They still served a small purpose, but are not very useful for fine manipulation. Vestige manipulators cost 0 EP.

Tails [1 EP for one]

Tails can be used for stabilization, arboreal movement, or striking. Many animals have tails that serve only to assist in movement (bird tails and so on) or have no purpose at all, as is the case for horses and dogs. As this is just the nature of their design, these cost 1 EP

However, tails that can strike, or are used as a "tentacle" cost 2 EP (basically, this is a tentacle, and should be treated as such). Vestige tails are simple, useless flaps of skin, and normally completely vanish within a few generations (though a bone structure may remain where they were). Such vestige tails cost 0 EP.

Rapid Regeneration [10 EP]

This ability allows the race to heal at a much faster rate. Instead of days, this race will recover a number of hits equal to its REC every *hour* when resting.

Instant Regeneration [20 EP]

This ability allows the race to heal at an astounding rate, even faster the Rapid Regeneration. Instead of days, this race will recover a number of hits equal to its REC every *minute* when resting.

Regrowth [10 EP per level]

This ability allows the race to regrow lost limbs or body parts. At Level 1, it can regrow tails, fingers, toes and other small, simple parts. At Level 2 it can regrow limbs, ears, and will not get permanent scar tissue. At Level 3 it may regrow more complex organs such as eyes, vital organs, and even recover from neurological damage to the spin and brain. The time it takes to regrow *one* lost body part is equal 30 days, divided by the level taken (so at Level 3 it would only take 10 days). If Rapid Regeneration is also taken, cut this time by half. If Instant Regeneration is taken, cut the time by ¼.

Natural Armor [1 EP per SPD]

Normally, an race has zero SPD armor. However, a shell, exoskeleton, thickly matted hair, tough skin, and so forth and call provide armor protection. It cost 1 EP to add

1 SPD of natural armor protection. Remember, 50 SPD equals one Kill of armor. Larger races may have as much armor as some vehicles or mecha.

Enhanced Metabolism [5 EP]

With this characteristic, a race's metabolic systems are much more finely tuned and efficient that the normal. This race uses energy, food, air, and water (or the equivalent) to its utmost advantage, excreting far less waste and thus requiring less food and water. The race's eating and drinking requirements are half. Furthermore, it can also hold its breath twice as long, and can go without water for extreme periods of time.

Chameleon [5 EP per Level]

Chameleon ability allows a race to change color in relation to its surroundings. Level 1 to 3 only allows for slight body color shifts and camouflage. Level 4 is partial invisibility, and level 5 is full invisibility. Thus, for each level, the race receives a +1 to Stealth.

At level 4 the race can turn, effectively, invisible, however, he still has a "fringe effect" around him. An invisible race with a fringe effect can be spotted at a range of 2 meters or less. At level 5 the race is totally invisible with no fringe effect. For Levels 1 to 3, only the Stealth bonus is of consequence (+1 through +3). For Levels 4 and 5 (invisible) there is the +4 and +5 Stealth bonus, as well as the bonuses from the invisibility effect.

If an opponent cannot make a Perception check, then he is at ½ (AGIL + Skill) in hand-to-hand and 0 (AGIL + Skill) at range. If the opponent can make a non-targeting PRE test, he is at ½ (AGIL + Skill) for both hand-to-hand and ranged combat. If the invisible creature is making a visible attack, the attacker is only a -1 to his AGIL, even at Range.

Spines [2 EP]

These can be spiked hair (like a porky pine) or bony spines (like a sea urchin). Either way, spines are normally for defense, not attack. A race with spines will automatically inflict damage to an attacker if it comes into direct contact. Spines normally do 1d4 damage on contact, but can be poisoned (see Poison Glands). If spines are on a striking tail or limb, that limb becomes a lethal weapon, and will do Killing damage instead of Stun damage.

Spikes [4 EP]

These are normally bony spikes or horns (as on a triceratops or stegosaurs, or modern horned animals.). Spikes are designed to be used aggressively. A race with spikes can make a charging or striking attack (depending on how the Spikes are arranged), and will do Punching damage +2 DC, but as Killing, instead of Stunning. If spikes are on a striking tail or limb, that limb becomes a lethal weapon, and will do Killing damage instead of Stun damage, with a +2 DC.

Claws [3 EP per limb]

Claws are weapons that are attached to limbs or fine manipulators, such as a lion's claws or bear's claws. They automatically make any damage done by that limb Killing instead of Stunning.

Pincer Claws [4 EP per limb]

Pincer claws are those such as on crabs, lobsters, or a praying mantis. They act as semi-fine manipulators, able to do some limited manipulation, but nothing as fine as true fine manipulators are capable of. Pincers are primarily weapons. They can grasp and hold

a target (as per Grab or Choke Hold maneuvers), and inflict terrible crushing damage to the target. When grasp, a pincer will inflict Punching damage to the target, but the damage is Killing instead of Stunning. Choke Hold is extremely deadly (giving an additional +2DC killing damage).

Crushing Jaw [1 EP]

This is a jaw that has strong crushing action. Most large land creatures have this type of mouth for chewing and eating plants and meat. Biting damage is 1 DC killing damage.

Fanged Jaw [2 EP]

This is a jaw that consists of two to four sharp fangs. Snakes and spider have this type of mouth. Biting does 2 DC killing damaged, but many fangs may also have poison glands.

Razor Jaw [3 EP]

This is a jaw which consist of dozens of razor sharp teeth. Many carnivorous animals have this type of mouth. Biting damage is equal to 3 DC.

Poison Glands [Various]

These are glands that secrete deadly poison. They may be placed in fangs, claws, spins, on the skin, or even in the mouth for direct spitting. It is assumed the races is immune to its own poison. Each gland cost a certain amount of EP, depending on how potent it is. One gland supplies poison to only specific body part. The possible parts are: Spines, Spikes, Claws, Fangs, Skin (for direct contact), or Blood (making the race toxic to eat). Thus, to poison both Claws and Fangs this must be bought twice. Spitting capability cost +2 EP, but it can be used at range, up to 10 meters.

Poison Potency	*Damage*	*Cost*
Irritant	1 DC Stun	1 EP
Mild	3 DC Stun	2 EP
Moderate	6 DC Stun	3 EP
Serious	1 DC Killing	4 EP
Severe	2 DC Killing	5 EP
Deadly	4 DC Killing	6 EP
Corrosive	+1 DC Killing	+1 EP
Acidic	+2 DC Killing	+2 EP
Paralyzing	Special	+2 EP
Instant Effect	Special	+2 EP

Normally, poisons take effect in 1D6 minutes, unless Instant Effect is taken. For Instant Effect, the poison takes effect in 1D6 seconds. This is common for deadly, acidic, or corrosive poison (Acidic poison is by default instant, but Corrosive is not). Paralyzing poison can paralyze its victim (temporarily) by interfering with signals from the nervous system to the brain. When infected by a paralyzing poison, the victim must make a successful BOD task roll vs. 18 or be paralyzed for 1D6 minutes. It should be remember that poisons may have a different effect, or no effect at all, on races of a different or alien metabolism.

Electroshock [3 EP per Level]

The race is able to produce an electric field through a series of electricity discharging organs. Each Level produces 1 DC Stun damage with a range of 1 meter. However, this uses a lot of energy, and so the creature must expend 2 END for every

level used. For instance, at level 4, the creature can generate an electroshock field out to 4 meters doing 4 DC of Stun damage, and it will expend 8 END points. This can be made to Killing damage for x2 Cost and x2 END expenditure. For a more superheroic Lighting Bolt throwing abilities, see Superpowers, Psionics, or Magic.

Enhanced Characteristics [5 EP per Level]

This race has characteristic enhancements far greater than what would be normally possible. Better neural connection, stronger bones or denser muscles, greater constitution, and so forth, Each +1 level to a primary characteristic cost 5 EP.

Reduced Characteristics [-5 EP per Level]

This race has reduced characteristics that are below those which should have naturally evolved. Each -1 level to a primary characteristic returns 5 EP to use elsewhere.

Enhanced Secondary Characteristics

Like enhanced Primary Characteristics, a race may have better secondary (derived)
characteristics, above and beyond what should normally be possible.

+2 SD & ED for 5 EP
+1 SPD for 10 EP
+1 REC for 5 EP
+2 END for 1 EP
+3 RES for +5 EP
+1 STUN for 1 EP
+1 HIT for 1 EP

Reduced Secondary Characteristics

Like reduced Primary Characteristics, a race may have poor secondary (derived) characteristics, below what should have naturally evolved.

-2 SD & ED returns 5 EP
-1 SPD returns 10 EP
-1 REC returns 5 EP
-2 END returns 1 EP
-3 RES returns 5 EP
-1 STUN returns 1 EP
-1 HIT returns 1 EP

Altered Time Scale [5 EP/-10 EP]

For some reason, this race is out of sync with the normal flow of time. This may be an accelerated or decelerated time-scale.

Accelerated Time Scale means the race's time scale runs much faster. Accelerated to 50% above normal (costing 5 EP) the race gains a +1 SPD, but it's apparent life span is cut by 75% (to that race, however, their life-span is normal). Communication is difficult (-1 PRE) because
members of this race talk very fast (but they act naturally to other members of their race). There may also be other time effects to consider. At double speed time scale (costing 10 EP), the race gains a +2 SPD, but its apparent life span is half. At x3 (costing 15 EP), the race gains +3 SPD, but its apparent life span is cut by 1/3. This can continue for x4, x5, x6, and so forth, but it becomes impractical.

Decelerated Time Scale means the race's time scale runs much slower. At 75% slower (returning 10 EP) the race has a -1 SPD, but its apparent life span is *increased* by

50%. Communication is difficult (-1 PRE) because members of this race talk so slow. At half time scale (costing -20 EP) the race has -2 SPD, but its apparent life span is double. This can continue for x.25, x.13, and so forth, but it becomes impractical.

Total Coordination [4 EP]

This race has a greatly enhanced coordination ability, able to fully coordinate their body and balance. This grants Ambidexterity, as well as a +3 to any AGIL roll to keep balance, and skills such as climbing, acrobatics, and athletics.

Metabolic Control [4 EP]

A race with full metabolic control can control all normally involuntary functions of the body, such as pulse, blood flow, respiration, digestion, endocrine, and adrenaline. Metabolic control gives the ability to Simulate Death and also reduces by 30% the amount of food, water, and oxygen need to stay alive.

Insubstantiality [50 EP/30 EP]

This race can become (or is) insubstantial, that is, made of ectoplasm, strange, quasi-physical particle, quantum energy-matter, exo-dimensional croutons, or whatever. For 50 EP this race can turn from its native form to a fully insubstantial form at will. For 30 EP it is permanently insubstantial. Note that for races with a Gaseous body, or a body of energy, sonic, or other strange physics, it may have some partially insubstantial advantages, but it is not fully insubstantial. Insubstantiality allows the being to pass through all solid objects as if they did not exist. However, it cannot carry, hold, or manipulate physical objects either. Physical attacks (killing and stunning) have no effect. Energy attacks do *half* damage, and mental and telepathic attacks will have effect as normal.

Insubstantial beings are still visible as a glowing ghostly image. It must take Chameleon at level 4 or 5 to be completely invisible and insubstantial.

Shapeshifting [5 EP/25 EP]

This is the ability for members of this race to change their form at will. There are two versions of Shapeshift. One is Singular Shifting, meaning the race has two forms which it can shift between (a werewolf, for instance, is a singular shapeshifter). It cost +5 EP each additional Singular form, so for 15 EP, a race could have 3 different forms. However, for a full 25 EP the race could be universal polymorphs, able to shift their bodies at a cellular or even molecular level, to turn into any creature or object they desire.

Each form should have the same basic characteristics as the individual. Physical Characteristics, however, can be shifted. That is, if turning into a lion, the points between DEX, REF, STR, CON, BOD, and MOVE can be slightly rearranged (by +/- 2 points, or as the GM wishes), and this allows the shapeshifter to better fit his new form. You cannot add new points to the Characteristics when you change form, only exchange your existing points. Mass should never change in a realistic setting, though the body can become more or less dense to fit a larger or smaller size. A polymorph (one who has many forms) must be familiar with the creature or object he is morphing into. Studying a form for an hour should be sufficient to memorize it.

When attempting to shift into the form of another being, it may be necessary to mimic their

voice. This requires the shapeshifter to have a skill in Mimicry. The shapeshifter must also possess that being's native communication method. He cannot mimic radio broadcast or other sophisticated traits unless they are part of his race's evolution.

Most Shapeshifters are Protocellular with a Neuro-chemical or Biochemical Distributed neurological system. Respiration is often Absorption and circulation is typically by Osmosis. The race must pay points for any traits they are capable of using. That is, if the race has Two Arms and they take a form with four arms, they can only use two at a time. This applies to all traits and features. There are no free deals in purchasing Shapeshifter.

Psionics

Some races may demonstrate psionic powers. Psionic powers (such as telepathy, teleportation, ESP, etc.) can be purchased for a race from Atomik Psioniks. Each category of a power can be bought at a certain level (ESP level 5), and there are a number of different ways to use the power (each method is a separate skill).

For instance, in Atomik Psioniks, Telepathy cost 2 PP per level. If a race has level 5 Telepathy, this would cost 10 PP, or 50 OP. This translates to 50 EP. However, because it is for an entire race, it is only an advantage outside their race. Therefore, racially granted psionic powers are half cost (a good deal!). Level 5 Telepathy, therefore, only cost 25 EP. The cost of additional enhancements for any *individual* cost the normal amount (for additional levels or other powers) and uses OP or PP. Members of a psionic race must also have a PSI characteristic. The race could have a default PSI which cost 5 EP per level (PSI 4 would cost 20 EP). See Atomik Psioniks for details.

Superpowers

There are many superpowers to chose from in the various *Champions: TNM* books. A superheroic alien race may have many superpowers above and beyond normal alien racial powers. A race may have superpowers, built as normal in *Champions: TNM*, and the final EP cost (for the race) is the power's PP x 3. That is, if the power cost 5 PP, it would only cost 15 EP. Just as for psionics, these powers are only special outside their native race, so the racial cost is lower (it would normally be PP x 5, but is only PP x 3). Using superpowers is a good way to give aliens even more diverse traits and abilities. Each power does require a Use Power Skill.

Magic

Some aliens may have magical powers. Often, these effects are created by technology, psionics, or superpowers. But, in a universe where real magic can exist, and alien race (or fantasy race!) may inherently have magical abilities. For magic, Atomik Magick should be used. A race with inherent magical powers has some native level of MAGE. Each level of MAGE cost 5 EP. Therefore, to have a MAGE characteristic at level 6 would cost 30 EP. Each spell is a skill that can be learned, just like any ordinary skill. Other magical options, such as the magical casting system, aptitudes, and so forth, can also be specified for the race. For instance, a race of Elves might have a native MAGE of 5, costing 25 EP, and the spell casting system Elven Magic. Individual elves may purchase a higher level of MAGE at character creation.

Scaling Races

Sometimes you need an alien species that isn't human sized. This works not unlike scaling mecha. When scaling races, x1 is human scale rather than x1/10.

Scale	BOD	STR	CON	MA	SP/DC	General	EP
x1/10	x1/3	x1/3	-2	x1/2	x1/5	x1/10	x1/5
x1/5	x1/2	x1/2	-1	x2/3	x1/3	x1/5	x1/3
x1	x1	x1	+0	x1	x1	x1	x1

x5	x3	x2	+1	x2	x3	x5	x5
x10	x5	x3	+2	x5	x10	x10	x10
x100	x25	x4	+3	x15	x50	x50	x100
x1000	x50	x5	+5	x30	x1000	x500	x2500

General covers anything not already listed.

Micro Scale is x1/10. This is the scale for insects, bugs and itty-bitty things.

Mini Scale is x1/5. This is for rodents and larger bugs. This is the smallest you should go for sentient races.

Human Scale is x1. This covers anything from the size of a house cat to a bear.

Dino Scale is x5. This is up to the size of elephants and dinosaurs. The Zentraedi from Macross fit into this scale.

Mekton Scale is x10. This is the same as 1:1 scale Mekton mecha. The largest of dinosaurs falls in this scale. Mekton scale creatures would weigh from 20 to 100 tons.

Super Scale is x100. This is the same as 1:10 scale Corvette mecha. Such creatures would be enormous, and likely confined to water, floating in the air of outer space. Dragons could fall in this scale. Creatures in this scale would range in the hundreds of tons.

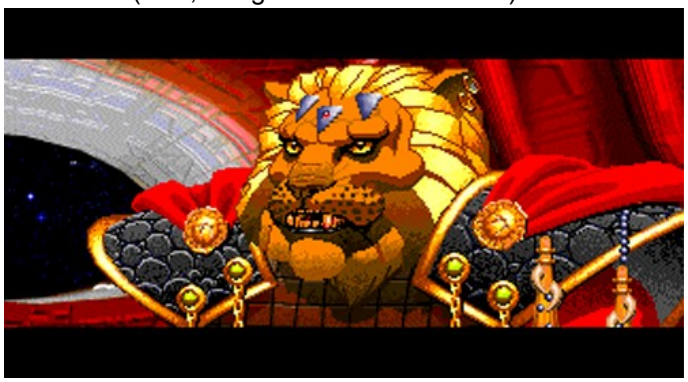
Ultra Scale is x1000. This is the same as 1:100 scale Starship mecha. Such creatures would weigh in the tens of thousands if not hundreds of thousands of tons.

Excessive Scale. This is so large that giving such a creature stats would be meaningless. How much BOD does a living planet have?

Aliens Not from Space?

The alien rules are useful for more than just space aliens. They can be used to detail out fantasy races such as orcs and elves, or even post-apocalyptic mutants on a war-torn futuristic Earth. Listed below are a handful of races detailed out with this system to give the GM an idea on how to assemble an alien species.

Kzinti (also, Wing Commander Kilrathi)



Context: Larry Niven's *Known Space* saga
Homeworld: Kzin
Form: Multicelluar Carbon Based, 100kg ave.,4 EP
Physical Exterior: Fur (orange or yellow), 2 EP
Cardiovascular: Close Centralized, 1 heart, 5 EP
Fluid Type: Warm Blooded, 4 EP
Respiratory: Air Lungs, hold breath 5 min, 6 EP
Bio-Stats
Life-Span: 50 years (unaugmented), 10 EP

Sleep-Time: 30% of the time, 5 EP
Vulnerabilities:
Radiation, Extreme, Stunning, -4 EP
Vacuum, Strong, Killing, -5 EP
Immunities: G-Forces, 10 Gs, 5 EP
Locomotion:
Biped, Lateral Walker, 4 EP
Partial Swim, 2 EP
Feeding Method: Carnivore, 3 EP
Sensory:
Sight, Optical with Nightvision 6 EP
Smell, Enhanced (+3 Percpt.), 8 EP
Taste, 2 EP
Touch, Direct, 2 EP
Hearing, Sonic, Acute (+1), 6 EP
Communication:
Vocal Comm, Sonic, 2 EP
Body Comm., 1 EP
Neural: Neuro-Electrochemical, Centralized, 5 EP
Special Features
Secondary Limbs, 1 pair, 4 EP
Fine Manipulators (both limbs), 6 EP
Claws (both paws), 6 EP
Vestige Manipulators (on feet), 0 EP
Tail, non-striking, 1 EP
Crushing Jaw, 1 EP
Total Coordination, 4 EP
Enhanced STR +3, 15 EP
Enhanced BOD +2, 10 EP
Reduced INT -1, -5 EP
Reduced PRE -1, -5 EP
Racial Complications: Kzinti Code of Honor, -5 EP
Scale: x1 Human-scale
TOTAL POINT COST: 105 EP
OP COST: 30 OP

The Kzinti are a race of feline (lion-like) warriors. The Kzinti are a proud and honor drive race, though brutal and unsympathetic to other races. The Kzinti expand their boarders through war and conquest, but their recent encounter with humanity proved fatal. Never once have the Kzinti been victorious in any of the Man-Kzin wars, and the Kzinti Empire has been reduced to a mere fraction of its former glory. The Kzinti race can also double for the Kilrathi of *Wing Commander*.

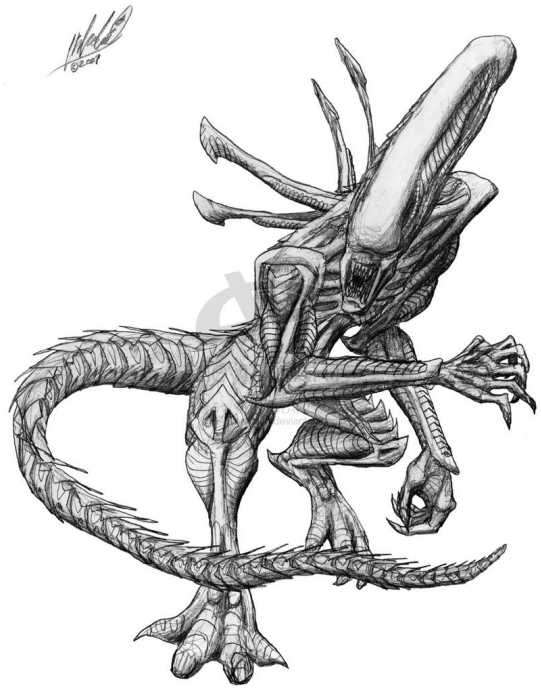
Vulcan

Context: Star Trek
Homeworld: Vulcan
Form: Multicelluar Carbon Based, 80kg ave., 4 EP
Physical Exterior: Skin (with hair follicles), 1 EP
Cardiovascular: Close Centralized, 1 heart, 5 EP
Fluid Type: Warm Blooded, 4 EP
Respiratory: Air Lungs, hold breath 5 min, 6 EP
Bio-Stats
Life-Span: 100 years (unaugmented), 20 EP
Sleep-Time: 20% of the time, 6 EP
Vulnerabilities:
Radiation, Severe, Killing, -6 EP
Vacuum, Strong, Killing, -5 EP
Immunities: G-Forces, 8 Gs, 4 EP
Locomotion:
Biped, Lateral Walker, 4 EP
Partial Swim, 2 EP
Feeding Method: Omnivore, 4 EP
Sensory:
Sight, Optical, 4 EP
Smell, 3 EP
Taste, 2 EP
Touch, Direct, 2 EP
Hearing, Sonic, 3 EP
Communication:
Vocal Comm, Sonic, 2 EP
Body Comm, 1 EP
Neural:
Neuro-Electrochemical, Centralized, 5 EP
Eidetic Memory, Lightning Calc., 4 EP
Special Features
Secondary Limbs, 1 pair, 4 EP
Fine Manipulators (both limbs), 6 EP
Vestige Manipulators (on feet), 0 EP
Vestige Tail, 0 EP
Crushing Jaw, 1 EP
Enhanced INT +1, 5 EP
Enhanced STR +1, 5 EP
Telepathy Level 2, 15 EP
Racial Complications:
No Emotions, -8 EP

Honesty, -5 EP
Scale: x1 Human-scale
TOTAL POINT COST: 95 EP
OP COST: 20 OP

Vulcans are a very humanoid race, the only difference being in their pointed ears and usage of copper-oxide instead of iron-oxide for blood. Vulcans are obsessively logical and suppress their emotions to the point of effectively nullifying them. Vulcans are culturally incapable of lying. They are telepathic.

Xenomorph of LV-426



Context: *Aliens* motion picture series
Homeworld: Unknown
Form: Multicelluar Carbon Based, 130kg ave.,4 EP
Physical Exterior: Exoskeleton 10 KD, 10 EP
Cardiovascular: Close Centralized, 1 heart, 5 EP
Fluid Type: Acidic - 7DC, 11 EP
Respiratory: Air Lungs, hold breath 30 min, 11 EP
Bio-Stats
Life-Span: 10 years (unaugmented), 2 EP
Sleep-Time: 20% of the time, 6 EP
Vulnerabilities: None
Immunities:
G-Forces, 10 Gs, 5 EP
Acid, 10 EP
Electricity, 15 EP
Locomotion:
Biped, Lateral Walker, 4 EP
Partial Swim, 2 EP
Feeding Method: Carnivore, 3 EP
Sensory:
Smell, Enhanced (+3), 8 EP
Taste, 2 EP
Touch, Direct, 2 EP

Touch, Ranged, 6 EP
Hearing, Sonic, Acute (+1) 6 EP

Communication:
Exotic Comm. (Telepathy), 8 EP
Hive Mentality, 5 EP

Neural: Neuro-Electrochemical, Centralized, 5 EP

Special Features
Secondary Limbs, 1 pair, 4 EP
Fine Manipulators (both limbs), 6 EP
Claws (both hands), 6 EP
Vestige Manipulators (on feet), 0 EP
Tail, (striking tentacle), 2 EP
Crushing Jaw, 1 EP
Rapid Regeneration, 10 EP
Enhanced Metabolism, 5 EP
Metabolic Control, 4 EP
Enhanced STR +3, 15 EP
Enhanced BOD +3, 15 EP
Reduced INT -2, -10 EP
Reduced PRE -2, -10 EP
Reduced TECH -1, -5 EP

Racial Complications: None
Scale: x1 Human-scale
TOTAL POINT COST: 176 EP
OP COST: 101 OP

They are the perfect product of artificial evolution, the epitome of alien genetic engineering and bio-warfare. Created by a now extinct alien civilization, the Aliens are the ultimate killing machines. They exist in four stages of development -- from egg to "facehugger", to chestburster to adult. Presented here is the adult, though the Queen Alien is much more powerful. Aliens have an exoskeleton giving them 10 KD/SDP of natural armor. They do not use visual sight as a sense, but rely on smell, hearing, and ranged touch (motion sensing).

Sylvan Elf

Context: Fantasy Genre
Form: Multicelluar Carbon Based, 80kg ave., 4 EP
Physical Exterior: Skin (with hair follicles), 1 EP
Cardiovascular: Close Centralized, 1 heart, 5 EP
Fluid Type: Warm Blooded, 4 EP
Respiratory: Air Lungs, hold breath 5 min, 6 EP
Bio-Stats
Life-Span:

100 years (unaugmented), 20 EP
Unaging Enhancement, 10 EP

Sleep-Time: 30% of the time, 5 EP

Vulnerabilities:

Radiation, Extreme, Stunning, -4 EP
Vacuum, Strong, Killing, -5 EP

Immunities: G-Forces, 6 Gs, 3 EP

Locomotion:

Biped, Lateral Walker, 4 EP
Partial Swim, 2 EP

Feeding Method: Omnivore, 4 EP

Sensory:

Sight, Optical with Nightvision, 6 EP
Enhanced Sight (+3), 5 EP
Smell, 3 EP
Taste, 2 EP
Touch, Direct, 2 EP
Hearing, Sonic, 3 EP

Communication:

Vocal Comm, Sonic, 2 EP
Body Comm, 1 EP

Neural:

Neuro-Electrochemical, Centralized, 5 EP
Direction Sense, 2 EP

Special Features

Secondary Limbs, 1 pair, 4 EP
Fine Manipulators (both limbs), 6 EP
Vestige Manipulators (on feet), 0 EP
Vestige Tail, 0 EP
Crushing Jaw, 1 EP
Total Coordination, 4 EP
Enhanced INT +1, 5 EP
Enhanced DEX +1, 5 EP
Reduced BOD -1, -5 EP
Reduced STR -1, -5 EP

Racial Complications: None

Scale: x1 Human-scale

TOTAL POINT COST: 105 EP

OP COST: 30 OP

Sylvan elves are a race of magical humanoids who inhabit forests and woodland areas. They are typically tall, thin, and have beautiful or handsome features. Elves have prominently pointed ears and sharp facial features. Most have fair skin and hair color ranges from dark to golden blond or even silver white. Sylvan Elves have a very long life span, upwards of 100 years on the average, though some elves live far longer, and they do not age past their mid-twenties. Elves are quite magical, and usually know several elemental and nature spells.

Great Dragon

Context: Fantasy Genre
Context: Fantasy Genre
Form: Multicelluar Carbon Based, 4 EP
Physical Exterior: Scales (5 KD), 5 EP
Cardiovascular: Close Centralized, 1 heart, 5 EP
Fluid Type: Cold Blooded, 2 EP
Respiratory: Air Lungs, hold breath 10 min, 7 EP
Bio-Stats
Life-Span: 300 years (unaugmented), 60 EP
Sleep-Time: 80% of the time, 0 EP
Vulnerabilities:
Radiation, Extreme, Stunning, -4 EP
Vacuum, Strong, Killing, -5 EP
Immunities:
G-Forces, 10 Gs, 5 EP
Heat/Fire, 10 EP
Locomotion:
Quadruped, 4 EP
Winged Flight, (MOVE x4), 5 EP
Feeding Method: Carnivore, 3 EP
Sensory:
Sight, Optical, 4 EP
Sight, Infrared, 6 EP
Smell, 3 EP
Taste, 2 EP
Touch, Direct, 2 EP
Hearing, Sonic, 3 EP
Communication: Vocal Comm, Sonic, 2 EP
Neural: Neuro-Electrochemical, Centralized, 5 EP
Special Features
Vestige Manipulators (on feet), 0 EP
Claws (all *four* feet), 12 EP
Tail, (striking tentacle), 2 EP
Spikes on Tail (+2 DC), 4 EP
Crushing Jaw, 1 EP
Natural Armor (+15 KD), 15 EP
Fiery Breath (5DC Killing Attack), 7 EP

Enhanced BOD +3, 15 EP
Enhanced STR +2, 10 EP
Racial Complications: None
Scale: x10 Mekton-scale, (4-K Armor)
TOTAL POINT COST: 1995 EP
OP COST: 1920 OP

Great Dragons are powerful magical beasts. They are quite enormous, most nearly a hundred meters from head to tail. They have a large body, long neck and tail, and have a similar appearance to a great reptile or dinosaur. Unlike some lesser dragons, Great Dragons have mighty wings that enable them to fly, some upwards of 60 km per hour. Great Dragons are at x10 Mekton Scale. Lesser Dragons are similar, but x5, and Ancient Dragons are x100 Scale! Great Dragons have a STR usually ranging between 10 to 14, and a BOD of 30 to 40. Thus, Great Dragons usually have between 150 to 200 Hits, or 3 to 4 Kills. Their scaly bodies also provide 4 Kills of armor protection! The Great Dragon's Fiery Breath does 5DC x 10, x10 as the Great Dragon has been scaled. This is 50 DC damage, or simply, a 3.6 Kill attack.

Draenei

Race: Draenei
Native Designation: ?
Homeworld: Argus, Draenor
Form: Multi-cellular Carbon-based, 80kg average [4 EP]
Physical Exterior: Skin with hair follicles [1 EP]
Cardiovascular: Close centralized, 1 heart [5 EP]
Fluid Type: Warm blooded [4 EP]
Respiratory: Air lungs, hold breath 5 minutes average [6 EP]
Lifespan: 60 year unaugmented [12 EP]
Sleep Time: 30% of the time [5 EP]
Vulnerabilities:
Radiation, Extreme, Stunning [-4 EP]
Vacuum, Strong, Killing [-5 EP]
Immunities
G-Forces: 8G [4 EP]
Locomotion
Biped Lateral Walker [4 EP]
Partial Swim [2 EP]
Feeding: Omnivore [4 EP]

Sensory
- Sight, Optical [4 EP]
- Smell [3 EP]
- Taste [2 EP]
- Touch, Direct [2 EP]
- Hearing, Sonic [3 EP]

Communication
- Vocal Communication, Sonic [2 EP]
- Body Communication [1 EP]

Neurological: Neuro-Electrochemical, Centralized [5 EP]
Special Features
- Secondary Limbs, 1 pair [4 EP]
- Tendrils, 2 Pair [2 EP]
- Fine Manipulators (both hands) [6 EP]
- Hooves (both feet) [0 EP]
- Prehensile Tail [2 EP]
- Fanged Jaw [2 EP]
- Enhanced PRE 2 [10 EP]
- Enhanced COOL 2 [10 EP]
- Inherent Magic: MAGE 2 [10 EP]

Racial Complications:
- Intolerance to Orcs (-10)
- Code of Honor (-10)

Scale: x1 (human)
Total Cost: 100 EP
OP Cost: 25 OP

The Draenei are a race of humanoids with digitigrade "jack" legs. Both genders have horns and four small, prehensile tendrils; males have them from the chin while females have them from the base of the skull. Males further have a ridged plate at the forehead. They are naturally inclined towards magic, and tend to take up occupations as priests, paladins or wizards. They have blue blood, and their skin is some shade of blue, blue-purple or blue-white. Their hair ranges from white, black, brown, deep blue and deep purple.

And the last one..

Martian, Green

Race: Martian, Green
- Native Designation: ?
- Homeworld: Mars (Ma'aleca'andra in their language)

Form: Proto-cellular Carbon-based, 80kg average [1 EP]
Physical Exterior: Skin with hair follicles [1 EP]
Cardiovascular: Osmosis [15 EP]

Fluid Type: Warm blooded [4 EP]
Respiratory: No Respiration [15 EP]
Lifespan: Effectively Immortal [40 EP]
Sleep Time: 30% of the time [5 EP]
Vulnerabilities:
Fire, Extreme, psychological/killing [-10 EP]
Immunities
G-Forces: 8G [4 EP]
Disease
Locomotion
Biped Lateral Walker [4 EP]
Partial Swim [2 EP]
Feeding: None [15 EP]
Sensory
Sight, Optical [4 EP]
Sight, Optical - Infrared [6 EP]
Smell [3 EP]
Taste [2 EP]
Touch, Direct [2 EP]
Hearing, Sonic [3 EP]
Hearing, Subsonic [3 EP]
Hearing, Ultrasonic [3 EP]
Electromagnetic Sense [5 EP]
Electromagnetic Resonance Imaging (MRI) [5 EP]
Communication
Vocal Communication, Sonic [2 EP]
Body Communication [1 EP]
Neurological: Neuro-Electrochemical, Decentralized [5 EP]
Special Features
Secondary Limbs, 1 pair [4 EP]
Fine Manipulators (both hands) [6 EP]
Vestige Manipulators (both feet) [0 EP]
Vestige Tail [0 EP]
Crushing Jaw [1 EP]
Rapid Regeneration [10 EP]
Regrowth 3 [30 EP]
Natural Armor, 30 SP [30 EP]
Total Coordination [4 EP]
Shapeshifter [25 EP]
Insubstantiality [50 EP]
Chameleon 4 [20 EP]
Enhanced STR 5 [50 EP]
Enhanced BOD 5 [50 EP]
Enhanced DEX 3 [30 EP]
Enhanced END 20 [10 EP]
Psionics - Telepathy 5 [25 EP]
Psionics - Telekinesis 5 [38 EP]
Heat Vision (damage from 1d6 hits to 3K) [15 EP]
Racial Complications:
Phobia, Fire (-10)
Scale: x1 (human)
Total Cost: 533 EP
OP Cost: 458 OP

The Green Martians are a race of superhuman shapeshifters, possessing formidable telepathic and telekinetic abilities. They have a deep fear of fire, the one thing they are really vulnerable to. As a result of their powers, they use the Mekton strength chart instead of the human one. Martians can fly, lift around

100,000kg, shrug off anti-Mecha weapons, control people's minds, shapeshift into all manner of creatures, turn invisible, become intangible, fire heat beams and otherwise completely dominate a non-superheroic campaign.

Crushing jaw, movement, secondary limbs, hands, etc apply to their "common" human-like form. While shapeshifting, they can have all manner of features. Their EP doesn't even really do their race justice and could be as much as twice this amount.

* Yes, I am aware that Miss Martian is a *white Martian*, but they seem to have all the same power sets.

Special Thanks, Mentions and So Forth

* Most of Chapter 12-13 stolen from various astrophysics websites, including Wikipedia
* Most of Chapter 14 stolen from Atomik Alienz, with updates for new discoveries